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DEVELOPMENT OF A 5,000 BBL, RUBBERIZED FABRIC FUEL STORAGE TANK—ETC(U)
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FINAL REPORT
DEVELOPMENT OF A 5000 BBL RUBBERIZED FABRIC FUEL STORAGE TANK, COLLAPSIBLE

Ronald L Sosnowski
Goodyear Aerospace Corporation
Engineered Fabrics Division
Akron, Ohio 44316

April, 1981

Phase II Final Technical Report for Period July 1980 - April, 1981

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This report describes the fabrication and testing of an experimental 5,000 barrel collapsible, rapidly deployable, rubberized fabric, temporary fuel storage tank. A State-of-the-Art study was performed in a prior phase of the effort to determine the tank configuration which best met project objectives using existing technology, following which the full-scale prototype and four 250 gallon models were fabricated and tested. Laboratory data are presented which demonstrate that the materials and construction		

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used met physical property and environmental resistance requirements. The field performance of the prototype will be evaluated by the Army at a later date. The report of the concept evaluation phase is included as an appendix to this report.

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SUMMARY

This report describes the development of an experimental 5000 barrel, rapidly deployable, collapsible, rubberized fabric tank for the temporary storage of petroleum fuels. The project was executed in two phases, the first of which involved a state-of-the-art evaluation of the concept, and the second the manufacture and test of four model tanks and a full scale experimental prototype. The original objective of the project was to develop a 7,000 to 10,000 barrel tank, but logistic considerations favored a smaller tank size. The concept evaluation phase concluded that tanks in the 5,000 - 10,000 barrel capacity range were within the state-of-the-art, but that a 5,000 barrel container was the best configuration considering cost, weight and tank ground area. It was concluded that a 68' by 68' tank made using 12 oz per sq yd nylon cloth coated with nitrile rubber would be the most efficient configuration for the prototype tank. A tank of this configuration and four 250 gallon models were fabricated in Phase II using existing production facilities and technology. Assembly tests on the models were performed successfully, as were destructive tests of materials used in fabricating the tanks. The prototype and model tanks were then delivered to the Army for field trials.

This report describes the work performed in Phase II of the contract, but the final Phase I report is attached as an Appendix for easy reference.

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PREFACE

The work described in this report was performed for the U S Army Mobility Equipment Research and Development Command under Contract Number DAAK70-79-C-0212 and was performed by the Engineered Fabrics Division (EFD) of the Goodyear Aerospace Corporation (GAC). All project management and design functions were performed in GAC's Akron, Ohio facilities. The experimental prototype and model units were fabricated in Rockmart, Georgia. Material and tank assembly testing was performed in facilities of the Goodyear Tire & Rubber Company which are also located in Akron, Ohio.

The project was initiated in October 1979 and completed in April 1981. Field trial performance testing of the experimental prototype will be conducted by the Army at Fort Clayton, Panama Canal Zone at a later date.

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INTRODUCTION**A. Scope of Report**

This report describes Phase II of the project which involved the fabrication and testing of a 5,000 barrel experimental, collapsible rapidly deployable, rubberized fabric, temporary bulk fuel storage tank, and four 250 gallon model tanks. The configuration for the prototype was established in Phase I of the project using state-of-the-art, cost-risk, and trade-off analyses. Operational and logistical characteristics of the recommended prototype configuration were also compared to existing temporary fuel storage systems. The report of the Phase I effort is included as Appendix A to this report for easy reference.

B. Overall Project Objective

The objective of this project was to design and develop a rapidly deployable 7,000 barrel collapsible fuel storage tank using state-of-the-art technology. To facilitate rapid deployment the tank envelope has to be as light as possible consistent with other operational requirements, and have minimum dimensions so the least amount of ground area is used in its deployment. The packaged tanks must be transportable by CH-47 and CH-53 helicopters. The operational characteristics of the CH-47 limit the packaged weight of the tank assembly to approximately 10,000 lbs.

The design goals were therefore as follows:

- a. Tank volume of 7,000 barrels
- b. Minimum tank volume of 5,000 barrels
- c. Minimize ground area
- d. Maximum area 75' x 120'
- e. Minimize tank weight
- f. Maximum weight of packaged tank, 10,000 lbs

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A secondary design goal was to provide a tank with a capacity of 10,000 barrels.

C. Approach

The project was divided into two phases. Phase I involved selecting a design configuration and materials for a full scale prototype container which was then manufactured and tested in Phase II.

Phase I was divided into a series of Tasks to systematically evaluate the state-of-the-art of materials and fabrication techniques applicable to tank design and manufacture, and to obtain data for conducting a trade-off study of various candidate tank design configurations. Large tank design parameters were established and candidate envelope materials selected. Samples of candidate materials were procured and tested.

Costs for producing various sized tanks were estimated and this data along with the design parameter data and candidate material physical property data were used in a cost-risk analysis. A trade-off analysis was performed and a leading candidate configuration selected. The expected operational and logistical characteristics of the leading configuration were compared to existing temporary fuel storage systems which addressed environmental considerations, maintainability, durability, ease of assembly, reliability, integrated logistic support, vulnerability, personnel safety, human factors and cost effectiveness.

The leading configuration was fabricated and tested in Phase II. Materials used in fabricating the prototype were subjected to destructive testing, and assembly tests were performed on two of four 250 gallon models which were built using the same materials and fabrication procedures as the prototype. Assembly tests were performed on models rather than the prototype unit to reduce the level of effort required for this testing and also to reduce the risk of damaging the prototype in multiple handlings and inspections. Field performance testing of the prototype will be conducted by the Army at a later date.

D. Organization

The project was conducted by the Engineered Fabrics Division of the Goodyear Aerospace Corporation in Akron, Ohio. Material property testing was performed in the Physical Test Laboratories of The Goodyear Tire and Rubber Company also in Akron, and assembly tests were performed in the companies Fuel Cell Test Facility in Suffield, Ohio. The prototype and model units were fabricated in the Engineered Fabrics Divisions's production facility located in Rockmart, Georgia.

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INVESTIGATION

A. Design

The design of the prototype tank was established in Phase I. The configuration which provides the least technical risk for the least cost, weight and flat area is a 5,000 barrel unit having flat dimensions of 68 ft by 68 ft. This tank will have a height of six foot eight inches at the top of the tank envelope when filled with fuel. This represents a fabric stress of 50 lbs per inch.

The fabric selected in Phase I is a cured, nitrile rubber coated, 12 oz per sq yd basket weave nylon fabric designated XA22A565. Coated fabric, XA22A579, was used in the prototype unit rather than the XA22A565 called out in the Phase I. The two fabrics are identical except for the finished width of the coated fabric. A nitrile coating compound was used in coating the cloth. Physical properties of these materials appear in the test section of this report.

The final prototype assembly design is shown in Figure 1. Fitting and accessory items were provided in accordance with the items identified in the Army's experimental purchase description for the unit. Four fittings were provided which included two 12 inch by 16 inch fill/discharge fittings, a drain fitting and a vent fitting as shown in Figure 1. Chafer patches were molded to both the inside and outside of the fabric pattern opposite each fitting and twenty six handles were molded around the periphery of the tank. Two 10 ft lengths of six inch MIL-H-370 hose were provided along with a valve assembly as shown in Figure 2. Quick disconnect couplings were provided on these accessories as well as the vent assembly. An emergency repair kit and installation instructions were also provided. Four 250 gallon models for assembly tests were also provided as shown in Figure 3.

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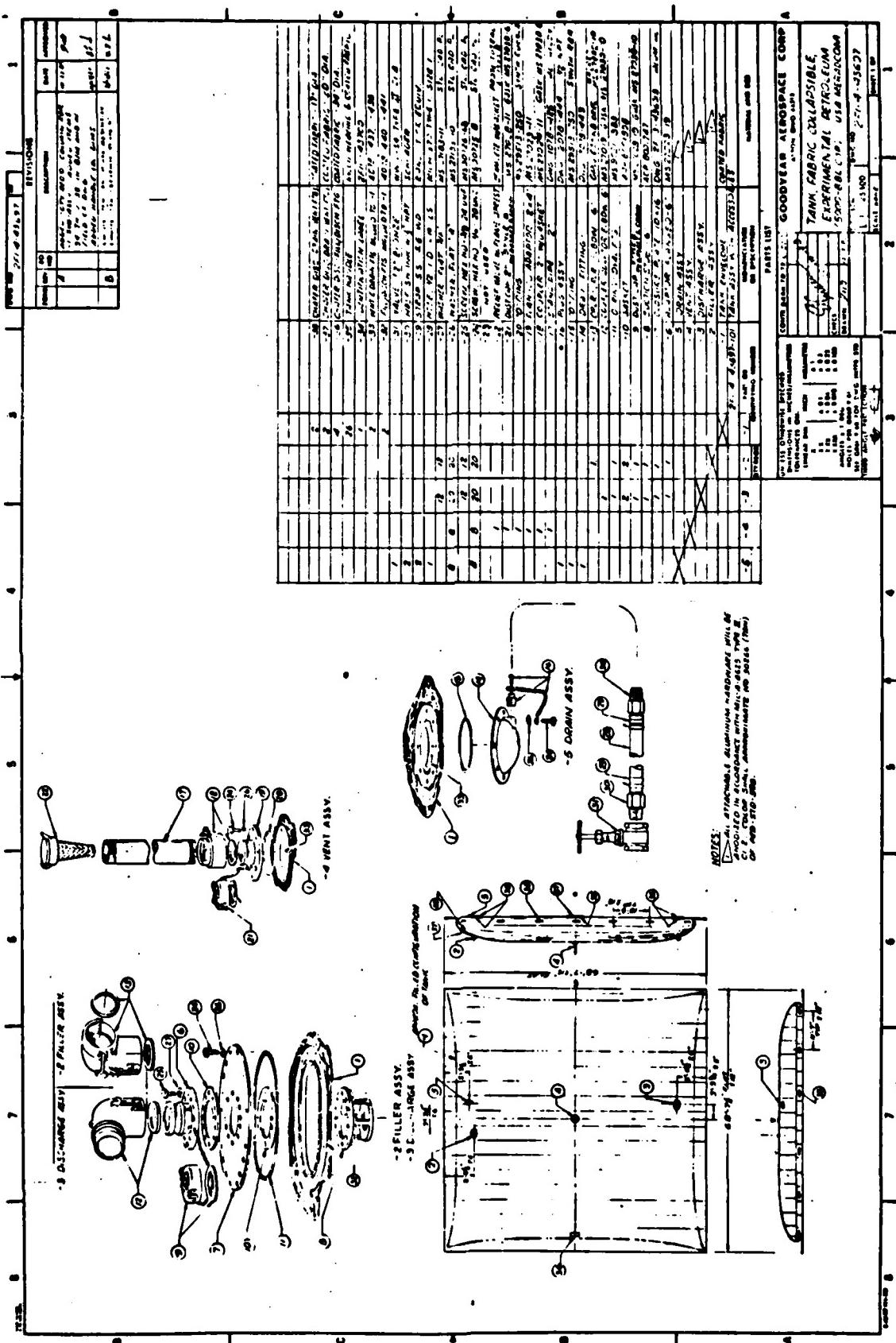
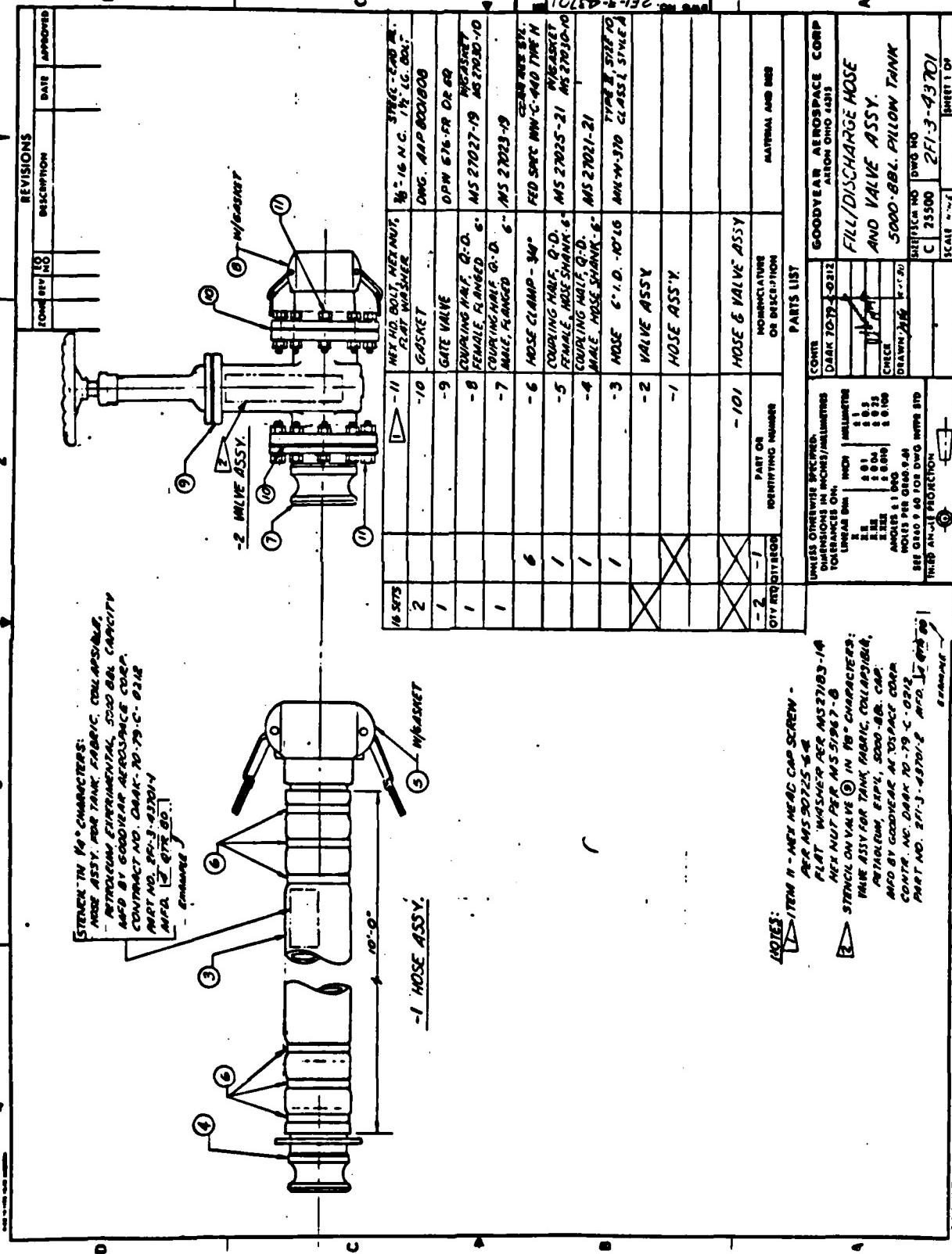


Figure 1--5,000 Barrel Tank Assembly



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Figure 3--250 Gallon Model Tank Assembly

Thirty six fabric patterns were used in fabricating the tank which were vulcanized together in a 70 ft seam press by a process proprietary to GAC. Overlap body seams were used which were $2\frac{1}{2}$ inches wide. This seam width is a half inch wider than that recommended in Phase I and will provide a stronger seam in the unit. All cut fabric edges in body patterns, chafers, fitting collars and handles were covered with gum tapes, prior to vulcanizing the parts, to seal all exposed fabric edges. Body seams were staggered so that they would not be on top of each other when the tank was folded for shipment. The fill/discharge fittings were located on opposite sides of the longitudinal center line for the same reason.

B. Fabrication

The prototype tank and models were fabricated in the Engineered Fabrics Division's Rockmart Georgia plant using facilities currently used in producing military and commercial PILLOW*tanks. These units were fabricated in November 1980 using standard PILLOW tank fabrication technology which is proprietary to GAC.

Body patterns were cut to proper length from cured XA22A579 coated fabric and fittings, chafers patches and handles were vulcanized to those patterns requiring them. The body patterns were then seamed together in a 70 ft long seam press to form the tank. The tank was then turned 90° and the end seams formed and cured. All cut fabric edges were covered with gum tapes to seal exposed fabric edges during cure. The final assembly was inspected, following which it was prepared for shipment.

The prototype unit was heavy and bulky but presented no unexpected handling problems in production and no special handling equipment was required. Fabrication was scheduled and organized so that the tank could be produced with the fewest possible number of movements. Handling problems were minimized by careful scheduling of fabrication operations.

*PILLOW is a registered trade mark of The Goodyear Tire & Rubber Co.

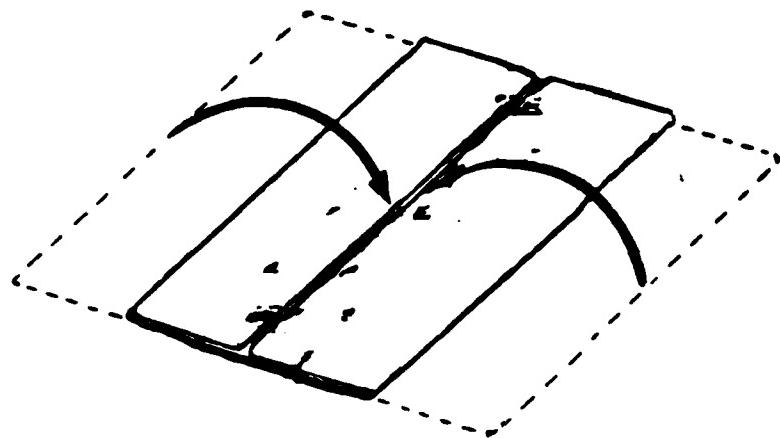
The packaging operation involved folding opposite edges of the tank in toward the center, making folds parallel with, but not on, body seams as shown in Figure 4. The folded edges formed were folded to the center of the tank once more following which the folded tank was rolled on a 15 inch corrugated steel pipe. It was felt that the fabric bundle on the pipe was too tight when packed in this way, particularly the first few wraps on the mandrel, and there was fear that the fill discharge fitting might have been damaged. The tank was unrolled, the fittings inspected and the steel tube discarded. There was no damage to the tank or fittings. The tank was then packaged by rolling both ends toward the center, without the mandrel. Three four inch webbing slings with "Delta" ring terminations had been placed under the tank prior to packaging to aid in the lifting operation. Four 1-3/4 inch webbing straps were similarly placed under the tank prior to packaging which were used to restrain the tank bundle from unrolling after packaging. Twelve people were required to complete the packaging operation with the aid of two fork lifts. The second packaging operation did not produce as neat a package as the first one. The two rolls were not square, and one roll was not as tight as is usually desireable. Additional webbing should be used under the full length of the tank to aid in the rolling operation.

C. Testing

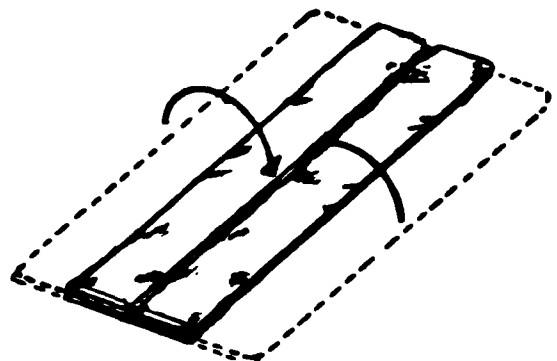
1. Destructive Tests of Prototype Materials

Destructive tests were performed on samples of materials taken from those used in fabricating the prototype unit. All sample materials were prepared and cured by methods identical to those used in fabricating the prototype. Tests were performed in accordance with the methods and requirements set out in the purchase description of the prototype unit. The non-standard test procedures are described in Appendix B for both destructive and assembly tests which are referenced to the representative paragraph of the purchase

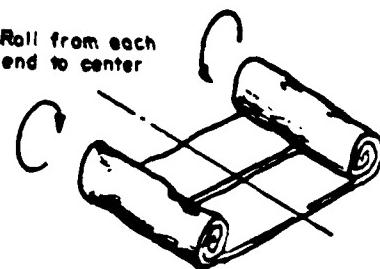
Fold each side over to center



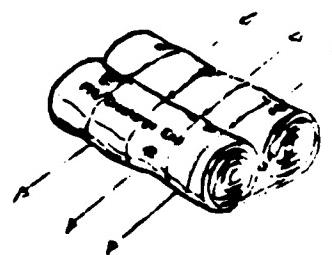
Fold each side over to center once again



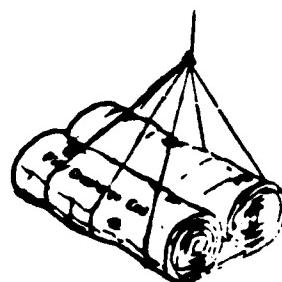
Roll from each end to center



Retain rolls with 1 3/4" webbing



~6,000 lbs.



Lift tank with 4" webbing lifting straps and place in shipping box

FIGURE 4 --TANK FOLDING AND RETRIEVAL

description. Destructive tests after exposure to various environmental conditions were performed on samples of cloth, coating compound, coated fabric, seams and fittings. Results of the testing appear in Tables 1 through 5 with reference to the test method or procedure used. All tests met design goals except the percent tensile strength retained on the coated fabric after Weatherometer exposure and the tensile strength of the body seam samples. The body seam samples failed in the fabric away from the seam indicating that the seam was stronger than the fabric. An examination of the samples showed that the yarns were skewed, which explains the lower value obtained. The weathering resistance test on the coated fabric resulted in a low value for percentage strength retained. This was largely due to the unusually high tensile strength value obtained on the coated fabric before exposure. The tensile strength after exposure was 581 x 431 lbs per inch which is acceptable considering that the prototype tank fabric will only be stressed at 50 lbs per inch.

2. Examinations

The prototype tank and its accessories passed all the requirements of Table 6.

GAC checks rubberized fabric tanks for leaks prior to shipment using an air inflation test. This test could not be performed on the prototype because it would have inflated to a structure approximately 43 foot high and there was no practical way of inspecting the surface for leaks with the unit standing this high.

TABLE I - Characteristics of 290N Cloth

Property	Goal	Test Method Of Fed Std No. 191	Actual Data
Thread count, warp & fill	Record	5050	40 x 40
Weave	Record	Visual	2 x 2 Basket
Weight oz/yd sq.	Record	5041	11.82
Thickness inches	Record	5030.2 ^{1/}	.027
Tearing strength warp & fill, 1bs.	Record	5134	138 x 143
Breaking strength warp & fill, 1bs/inch	Record	5104 <u>2/</u>	729 x 721
Weathering resistance after 100 hrs exposure at 5% elongation	50% retention of initial breaking strength (min)	5804 <u>2/</u>	
		5104 <u>3/</u>	99.45 x 105.13

Footnotes:

- 1/ The edges of the tear-test specimen were coated by dipping into an adhesive that precluded yarn slipping while under test.
- 2/ Alternate corex D filters removed. Specimens were ravelled for Method 5104 after accelerated weathering.
- 3/ Ends of specimens for Breaking Strength Test were coated by dipping into an adhesive that precluded yarn slipping under test. Only those parts that were held in the clamps during test were treated.

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TABLE 2 - Characteristics of Cured Elastomeric Coating Compound M908

Property	Goal	Test Para or Test Method of Fed Test Method Std 601	Actual Data
Initial			
Tensile Strength, psi	Record	4111	1914
Stress at 200% Elongation, psi	Record	4131	754
Ultimate Elongation, %	Record	4121	630
After Immersion in Distilled Water (ph of 7.0 \pm 0.2) at 160°F \pm 2°F			
Volume Change			
14 Day, %	Record	6211	+8.9
70 Day, %	Record	6211	+6.0
Initial Tensile Strength Retained (1)			
14 Day, % (min)	60	6111 (Para 4.8.1 of	89.4
70 Day, % (min)	40	Method 6111 Applies)	87.8
After Immersion in ASTM D-471, Ref Fuel D (4)			
Volume Change			
14 Day, %	Record	6211	+12.8
70 Day, %	Record	6211	+11.8
Initial Tensile Strength Retained			
14 Day, % (min)	40	6111 (Para 4.8.1 of	63.6
70 Day, % (min)	30	Method 6111 Applies)	57.5
After Accelerated Weathering For 500 hrs (3)			
Initial Tensile Strength Retained (1),% (min)	75		84.8
Fuel Contamination			
Unwashed Existent Gum, mg/100 ml (max)	20	4.4.1	12.6
Heptane Washed Existent Gum, mg/100 ml(max)	5	4.4.1	0.1

NOTES: (on next page)

NOTES:

- (1) The percentage tensile strength retained is:

Tensile strength retained after immersion or weathering x 100

Initial tensile strength value actually obtained (average of 3 or more samples)

- (2) Tolerance for immersion periods: \pm 2 hours
(3) Exposed at 10% elongation with alternate Corex D filters in place.
(4) 60% iso-octane and 40% toluene

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TABLE 3 - Characteristics of Coated Fabric XA22A579 1/

PROPERTY	GOAL	TEST PARAGRAPH OR TEST METHOD OF FED STD NO 191	ACTUAL DATA
Thickness, inches	Record	5030-1	.070
Weight, oz per sq yd	Record	5041	.071 .27
Diffusion rate	.10 f1 oz/sq ft per 24 hrs (max)	4.4.2	.0919
Tearing strength, warp & fill	50 pounds (min)	51.34	105 x 89
Breaking strength, warp & fill	650 lbs/inch (min)	51022/	828 x 730
Weathering resistance after 500 hrs exposure at 100 lbs/in. (initial tension), warp & fill	80% retention of initial breaking strength (min)	5804/51023/	70.16 x 59.04
Puncture resistance	200 pounds (min)	4.4.3/5120	240
Low temperature crease resistance:	No cracking, peeling, or delaminating	4.4.4	No Cracking
(a) Appearance after unfolding	.10 f1 oz/sq ft per 24 hrs (max)	4.4.2	.09835
(b) Diffusion rate after low temperature crease resistant test	No cracking, blistering, or delamination of coating. Retention of breaking strength 50% (min)	57625/	OK 99.6% x 82.7%/ 1
Fungus resistance	Specimens to separate within 5 seconds	4.4.5	0K
Blocking	20 pounds/in (min)	4.4.6	86.3
Coating adhesion (initial)			
Coating adhesion after immersion in distilled water at 160F ± 20F for the following durations:	10 lbs/in (or 30% of initial) ^{4/} (min)	4.4.6	83(96.2%)
14 Days	5 lbs/in (or 20% of initial) ^{4/} (min)	4.4.6	75(86.9%)
42 Days			
Coating adhesion after fuel immersion in reference fuel D at 6/ 160F - 20F for the following durations:	10 lbs/in (or 40% of initial) ^{4/} (min)	4.4.6	60(69.5%)
14 Days	10 lbs/in (or 30% of initial) ^{4/} (min)	4.4.6	51(59.1%)

FOOTNOTES: (see next page)

FOOTNOTES: (Table 3)

- 1/ Properties after cure
- 2/ Specimens were prepared by cutting parallel to the threads of the fabric.
- 3/ Specimens were tensioned in the direction of the 6-inch length, under a stress of 100 lb/in \pm 5 lb/in for 60 seconds. While still under stress the specimens were clamped to maintain the initial (one minute) elongation without slippage. While still so elongated, specimens were exposed by Method 5804 of FED TEST METHOD STD 191.
- 4/ Whichever is the greater requirement
- 5/ Method 5762 except that the specimens were prepared by Note 1/ after soil burial.
- 6/ Reference fuel D is ASTM D-471, 60% iso-octane and 40% toluene.
- 7/ Retained after 56 days

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TABLE 4 - Characteristics of Seams 1/

PROPERTY	GOAL	TEST METHOD OR FED STD NO 601	BODY SEAM ACTUAL DATA END SEAM
Breaking strength (initial)	650 lbs/in (min) ^{2/}	8311/4.4.7	555 692
Breaking strength after immersion in distilled water at 160°F ± 20°F for the following durations: 14 days 42 days	500 lbs/in (min) 450 lbs/in (min)	8311/6001/4.4.7 8311/6001/4.4.7	463 432 596 607
Breaking strength after immersion in ref fuel D 4/ at 160°F ± 20°F for the following durations: 14 days 42 days	500 lbs/in (min) 450 lbs/in (min)	8311/6001/4.4.7 8311/6001/4.4.7	580 542 673 746
Dead load shear resistance under 100 lb/in stress at 200°F for 8 hrs	125 in slippage (max) 20 lbs/in (min)	8311/6001/4.4.7 8011	0K 93 0K 93
Peel adhesion (initial)			
Peel adhesion after immersion in distilled water at 160°F ± 20°F for the following durations: 14 days 42 days	10 lbs/in (or 30% of initial)(min) ^{3/} 5 lbs/in (or 20% of initial)(min) ^{3/}	8011/6001/4.4.7 8011/6001/4.4.7	80 (86.2%) 71 (76.3%) 80 (86.2%) 71 (76.3%)
Peel adhesion after immersion in ref fuel D 4/ at 160°F ± 20°F for the following durations: 14 days 42 days	10 lbs/in (or 40% of initial)(min) ^{3/} 10 lbs/in (or 30% of initial)(min) ^{3/}	8011/6001/4.4.7 8011/6001/4.4.7	49 (52.6%) 40 (43.0%) 49 (52.6%) 40 (43.0%)

FOOTNOTES:

1/ Properties after cure

2/ All specimens broke in the coated fabric.

3/ Whichever is the greater requirement

4/ Reference fuel D is ASTM D-471, a blend of 60% iso-octane and 40% toluene

TABLE 5 - Characteristics of Bonded Fittings ^{1/}

PROPERTY	GOAL	TEST PARAGRAPH OR TEST METHOD OF FED STD NO 601	ACTUAL DATA
Aluminum to coated fabric bond strength (initial)	600 lbs/in (min)	4.4.9 & 4.4.9.1	98 ¹
Bond strength of fitting after immersion in distilled water at 160°F ± 20°F for the following durations:			
14 days	450 lbs/in (min)	4.4.9.2	89 ¹
42 days	400 lbs/in (min)	4.4.9.2	94 ¹
Bond strength of fitting after fuel immersion in ref fuel D 3/ at 160°F ± 20°F for the following durations:			
14 days	450 lbs/in (min)	4.4.9.2	574
42 days	400 lbs/in (min)	4.4.9.2	82 ²
Dead load sheer resistance under 100 lbs/in stress at 200°F for 8 hrs	.125 in slippage (max)	4.4.9.3	0 ¹
Peel adhesion of aluminum strip to coated fabric (initial)	20 lbs/in (min)	4.4.10.1	6 ¹
Peel adhesion of aluminum strip to coated fabric after immersion in distilled water at 160°F ± 20°F for the following durations:			
14 days	10 lbs/in (or 30% of initial) (min) 2/	8031/4.4.10.1	50 (81.9%)
42 days	5 lbs/in (or 20% of initial) (min) 2/	8031/4.4.10.1	58 (95.0%)
Peel adhesion of aluminum strip to coated fabric after immersion in ref fuel D 3/ at 160°F ± 20°F for the following durations:			
14 days	10 lbs/in (or 40% of initial) (min) 2/	8031/4.4.10.1	29.5 (48.3%)
42 days	10 lbs/in (or 30% of initial) (min) 2/	8031/4.4.10.1	38 (62.2%)

FOOTNOTES:

^{1/} Properties after cure^{2/} Whichever is greater requirement^{3/} Reference fuel D is ASTM D-471, a blend of 60% iso-octane and 40% toluene.

TABLE 6 - Examination Schedule

Examination Number	Examination Description	Requirement Paragraph
101.	Dimensions as specified	3.4
102.	Materials as specified	3.3
103.	Fittings as specified	3.4.4
104.	Chafing patches and handles as specified	3.4.2
105.	Finish of fittings as specified	3.4.4.1
106.	Fittings, chafing patches, or handles located as specified	Figure 1
107.	Splices and seams coincident or seams coincident with tank fittings.	3.4.1
108.	O-rings lubricated as specified	
109.	Edges of coated fabric covered as specified	3.4.1
110.	Emergency repair items as specified	3.6
111.	Identification label as specified	3.7
112.	Workmanship as specified	3.8
113.	Blisters or pinholes in coated fabric	3.3.3
114.	Extraneous material inside tank	3.8
115.	Barrier film loose or evidence of coating delamination.	3.3.3
116.	Seam separating (peel back) greater than 1/4 inch.	3.8
117.	Seam slippage greater than 1/8 inch	3.8
118.	Accessories as specified	3.5

3. Assembly Tests

No assembly tests were performed on the prototype unit for reasons previously cited. The bulk of these tests were performed on two of the four 250 gallon model tanks which were produced using identical materials, construction and fabrication procedures as those used in the prototype tank.

Assembly tests of a tank handle and the vent assembly were performed in accordance with Para 4.3.3.1 and 4.3.3.2 of the test procedures in Appendix B and were passed successfully. The tank handle test was performed on a sample rather than one from the tank. A special test fixture was used to restrain the sample during load application. The sample was prepared using the same materials and procedures as those used to vulcanize handles to the prototype tank.

The cold and hot unfolding tests, water stand test and internal inspection were performed on two model tanks in accordance with Para 4.3.3.3, 4.3.3.4, 4.3.3.5 and 4.3.3.6.1 of the test procedures. Loads equivalent to those expected in the full scale prototype were imposed on the models during the cold and hot unfolding. Since it had not been established whether the prototype would be rolled on a mandrel after folding, or have both ends rolled toward the center of the package with no mandrel, a model was tested in each of these configurations. The finished dimensions and footprint of the packaged prototype were estimated for each of these configurations to determine the load per square foot imposed on the bottom most ply of fabric, based upon an estimated prototype weight of 4,600 lbs with the mandrel and 4,350 lbs without. The prototype rolled on a mandrel was estimated to have a footprint of 5 ft x 20 ft so the load imposed on the bottom most ply of fabric would be 46 lbs/sq ft. The double rolled prototype was estimated to have a 6 ft x 20 ft footprint with a load of 36.25 lbs/sq ft.

The models weighed 62 lbs and the unit folded in thirds rolled on a mandrel had a footprint of 2.0 ft by 3.5 ft or 7.0 sq ft. The mandrel weighed 122 lbs therefore, the model required 46 lbs/sq ft applied to a 7 sq ft footprint or 322 lbs. From this was subtracted the weight of the model and mandrel to determine the additional weight required of 138 lbs. 135 lbs. was actually used in the test.

The model folded in thirds with both ends rolled to center produced a package size of 3 ft by 3.5 ft or 10.5 sq ft, therefore the model required 36.25 lbs/sq ft applied to it or 381 lbs. The model weighed 62 lbs therefore 320 lbs of uniformly distributed weight was required on the model. The weight of the plywood required to support the weights was considered to have negligible weight.

Two model tanks were randomly selected from the four produced and were visually examined prior to testing to make sure there was no damage in transit to the test site.

Both models were first folded in thirds. One model was rolled on a 15 inch diameter galvanized, corrugated steel pipe mandrel and tied down with a cloth tape. The model was placed in a temperature chamber and 135 lbs of weight was placed inside the mandrel over the tank. On the second folded model, the ends were rolled toward the center, and it was also placed in the temperature chamber. A 3/4 inch plywood board was placed on top of it and 320 lbs of uniformly distributed weight were placed on the board. The temperature of the chamber was lowered to -30°F and after 24 hours was raised to -25°F. After 22 hours at -25°F the two model tanks were removed from the test chamber and slowly unfolded and unrolled. There were no signs of cracking or delaminating in either model. Following the cold test the models were reinstalled in the temperature chamber as described above and subjected to 24 hrs exposure at 160°F following which they were again unrolled and unfolded with no evidence of failure. Each unit was then filled

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with 250 gallons of water and allowed to stand for 24 hours at ambient temperature. There were no signs of leakage or seepage. Both tanks were visually inspected internally and externally and no discrepancies found. All four models were then shipped to the Army.

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CONCLUSIONS

A 5,000 barrel elastomeric coated fabric, collapsible, self-supporting, rapidly deployable fuel storage tank can be produced using state-of-the-art materials and fabrication technology. The experimental tank produced in this project met all required design goals, except weathering resistance.

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RECOMMENDATIONS

It is recommended that the 5000 barrel prototype tank be tested to determine its performance in a field environment. The tank should be filled with 210,000 gallons of water and allowed to stand for 30 days and examined for leaks. Following this 20,000 gallons of water should be replaced with fuel and a 30 day stand test repeated. The use of water in place of fuel in this testing will save considerable test cost while at the same time providing a fuel environment on a portion of the tank surface to evaluate the resistance of tank materials to fuel. Following this stand test, an additional 21,000 gallons of fluid, water or fuel, should be introduced and maintained for 4 hours to evaluate the construction in an overload condition. Measurement of height of fluid in the vent fitting should be made during each of these operations at least once a day to provide data on tank stress at each condition. Following these tests the tank should be cycled between 75% and 100% of design capacity in 30 day intervals for six cycles.

The four 250 gallon model tanks should each be filled with a different fuel representative of those which might be used in the 5000 barrel prototype in actual service. This will demonstrate the durability of the materials used in the tank to the fuels which the 5000 barrel tank might see in service.

The prototype tank shipped to the Army was not a very neat package in that the tank was not rolled up squarely. The packaging operation and the neatness of the package will affect deployment to some extent with respect to properly orientating the tank in its berm. In the future, tanks will be packaged better as production personnel become more familiar with the product. It is recommended, however, that consideration be given to the use of webbing rolled up with the tank to aid in packaging, deployment and eventual retrieval. It is also recommended that the shipping container be redesigned now that the packaging technique and dimensions have been established.

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GOODYEAR AEROSPACE CORPORATION

AKRON, OHIO 44315

FINAL TECHNICAL REPORT
PHASE I - STATE-OF-THE-ART STUDY FOR
DESIGN AND DEVELOPMENT OF A 7000 BARREL
COLLAPSIBLE FABRIC (ELASTOMERIC)
PETROLEUM FUEL TANK ASSEMBLY

PREPARED FOR
U.S. ARMY MOBILITY EQUIPMENT RESEARCH AND
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APPENDIX A

PHASE I - FINAL REPORT

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SECTION I -- INTRODUCTION**A. General**

This report describes the results of a state-of-the-art study of collapsible fabric petroleum fuel tanks. The purpose of this study is to establish state-of-the-art design parameters and to select candidate state-of-the-art materials for further evaluation as part of the concept evaluation phase of a project to "Design and Develop a 7000 Barrel Collapsible Fabric (Elastomeric) Petroleum Fuel Tank Assembly" for the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) under contract number DAAK70-79-C-0212.

B. Overall Project Objective

The objective of this project is to design and develop a rapidly deployable 7000 barrel collapsible fuel storage tank using state-of-the-art technology. To facilitate rapid deployment the tank envelope must be as light as possible consistent with other operational requirements, and have minimum dimensions so the least amount of ground area is used in its deployment. The packaged tanks must be transportable by CH-47 and Ch-53 helicopters. The operational characteristics of the CH-47 limit the packaged weight of the tank assembly to approximately 10,000 lbs.

The design goals are therefore as follows:

- a. Tank volume of 7000 barrels
- b. Minimum tank volume of 5000 barrels
- c. Minimize ground area
- d. Maximum area 75' x 120'
- e. Minimize tank weight
- f. Maximum weight of packaged tank, 10,000 lbs

A secondary design goal is to provide a tank with a capacity of 10,000 barrels.

100-1517-380
REF: FOI

Design parameters, cost and other data will be established as necessary to conduct a trade off determination of the various technical approaches considered for storing bulk fuels in collapsible containers in undeveloped theaters. This effort will evaluate the various risks involved for each design consideration including environmental, maintainability and durability, ease of assembly, reliability, integrated logistic support, vulnerability, personnel safety, human factors and cost effectiveness.

The project is divided into two phases. Phase I involves selecting a design configuration and materials for manufacturing a full scale prototype container which will be manufactured and tested in Phase II. Phase I is divided into a series of Tasks to systematically evaluate the state-of-the-art of materials and fabrication techniques applicable to tank design and manufacture, and to obtain data for conducting a trade-off study on various tank design configurations. The Phase I tasks are as follows:

- Task 1 - Establish Large Tank Design Parameters
- Task 2 - Review the State-Of-The-Art of Fabrication Techniques
- Task 3 - Select Candidate Materials
- Task 4 - Analyze Properties of Leading Candidate Materials
- Task 5 - Trade Off Analysis
- Task 6 - Select Material for Prototype Manufacture
- Task 7 - Test Samples for MERADCOM

C. Scope of This Report

This report presents the results of the Phase I effort. A recommendation is made of the leading candidate configuration for a prototype container based on the state-of-the-art studies performed, and a trade off analysis of tank properties and cost.

SECTION II -- DISCUSSION

A. Literature Survey

A literature search was conducted to obtain data for establishing the state-of-the-art of rubberized fabric containers. The documents used in this report are shown in the Reference Section and are referred to by number.

B. Historical Data

Tables 1 through 6 present data on collapsible fuel tanks previously manufactured by Goodyear and the physical properties of the materials used in them. This data will be referenced in the discussions for Task 1, Preliminary Design Analysis, and Task 3, Selection of Candidate Materials.

C. Preliminary Design Analysis - Task 1

1. General

The objective of Task 1 is to establish the parametric relationships between tank volume, flat dimensions and the related stresses acting on the fabric, seams and fittings, considering the project goals and constraints including:

- a. Designs which require a minimum of ground area with a maximum of 75 x 120 feet.
- b. Packaged tank weight limits of 10,000 pounds with tank envelope weights of less than 8,000 pounds.
- c. Fabric tensile strengths greater than 1,000 lbs/inch.
- d. Fabric tear strengths greater than 50 lbs.
- e. Fabric puncture values greater than 200 lbs.
- f. Seam strengths greater than 1,000 lbs/inch, but not less than the strength of the fabric from which they are made.
- g. Using state-of-the-art design techniques and materials.
- h. Keeping in mind the logistical, economic, personnel, safety, deployment, environmental and other factors which must be considered in the selection of the final design.

100-1507-101-300
REF: 101

TABLE 1 -- TYPICAL PILLOW TANK CONTRACTS

<u>No.</u>	<u>Project Title</u>	<u>Contract No.</u>	<u>Issuing Agency</u>	<u>Period of Performance</u>	<u>Test Reports</u>	<u>Ref No.</u>
1	20,000 Gal PILLOW* Tank (1426 Units)	M00027-8-C-0038	U.S. Marine Corps	1979 - 1982	GAC 19-1733	1
2	10,000 Gal PILLOW Tanks (310 Units)	QB2116010242985 QB2118005064447	West German Defense Ministry	1979 (1963)	474F-3427-FC	2
3	3,000 Gal PILLOW Tanks (257 Units)	DAAK01-77-C-5289	U.S. Army	1978	GAC 19-1155	3
4	Seamless Kevlar Tube for PILLOW Tanks	DAAK70-77-C-0118	U.S. Army, MERADCOM	1978	GAC 19-1208	4
5	Seamless Nylon Tube For PILLOW Tanks (28 ft x 28 ft)	DAAG53-75-C-0249	U.S. Army MERADCOM	1976	GAC 19-1035	5
6	50,000 Gal Fuel Containers	N66314-74-C-7186	Mare Isle Naval Shipyard	1974	CDR 229	6
7	210,000 Gal PILLOW Tank	DAAK02-67-0-0108	USA ERDL	1967	6024-FC	7
8	10,000 Gallon PILLOW Tank	DSA-700-68-C-8067	Defense Supply Agency	1968	GAC 19-544	8

TABLE 2 -- HISTORICAL DATA PILLOW TANK FABRIC CLOTHS

No.	Year	Size	Cloth Code	Denier	Weave	Ends in.	Wt. Oz/yd ²	T. Ult W	Tear F	T. Ult %	After 100 Hrs	Ref No.
1	1979	20,000	3640N	840X	2x2	42x	9.58	736 x 694	122 x 124	81 x 90	1	
	1982	Gallon	Nylon	840	Basket	42	(10.0)	(600x600)	(100x100)			
2	1979	10,000	3592N	840X	Plain	32x	7.5	503x484	82 x 75	-	2	
		Gallon	Nylon	840		32		(400x400)	(50x50)			
3	1978	3,000	3634N	840X	2 x 2	35x	(8.00)	(450x450)	(100x100)	-	3	
		Gallon	Nylon	840	Basket	35						
4	1978	80x80 in tube	RF-365	1000X	2x1	36x	9.5	1231x1283	264x274	45x50*	4	
			Kevlar	2000	Mod.	18						
A-5	5	1976	28x28 ft tube	RF-260	1050y	2x2	34x	10.1	561x588	141x157	85x104	5
			Nylon	1050	Basket	34						
6	1974	50,000	3603N	1050X	2 x 2	40x	12.03	713x716	142x145	99x96%	6	
		Gallon	Nylon	1050	Basket	40		(650x650)	(125x125)			
7	1967	210,000	3603N	1050X	2 x 2	40x	12.03	713x716	142x145	99x96%	7	
		Gallon	Nylon	1050	Basket	40		(650x650)	(125x125)			
8	1968	10,000	3602N	840X	Plain	35x	(815)	(450x450)	(55x55)	-	8	
		Gallon	Nylon	840		35						

*Kevlar 1% instead of 5% elongation (nylon) (specification minimum values)

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TABLE 3 --- HISTORICAL DATA - PILLOW TANK COATING COMPOUNDS

No.	Year	Size	Coating Code/Type	Tensile Lbs./In ²	Elong. Ult %	Tensile %			After 47 Days	After 500 Hrs	Fuel Con- tamination Mg/100 ML	Ref No.
						Water	Fuel	Water				
1	1979	20,000	M-908 (Nitrile)	1827	545	95.2	74.6	106	74.6	65	12.6 Un- washed 0.1 Washed	1
2	1979	10,000	H-348-B (Nitrile)	1525	500	-	-	-	-	95	98	53-56 Non- Volatile 4-5 Stoved
3	1978	3,000	M-901 (Nitrile)	1914	450	100	57.8	-	-	0 ₂ Bomb	24 Hr	20.7 Unwashed 7.25 Washed
			Gallon									
4	1978	80x80	82C39 (Polyurethane)	3277	410	94	53	82	48	-	-	4
		in tube	D1666F609	3349	440	107	51	93	48	-	92	20.7 Unwashed 7.25 Washed
			82C09	2160	340	77	58	89	51	-	91	
5	1976	28x28	80C29 (Polyurethane)	5250	370	72	63	-	53	-	92	7.0 Unwashed 2.1 Washed
		ft tube	81C03	4259	370	-	-	-	-	-	93	
			D1666F516	4308	417	65	43	-	36	-	88	
			D1666F514	4935	360	60	44	3	41	-	-	
6	1974	50,000	81C66; I (Polyurethane)	3444	378	84*	57	87*	106	-	-	14.0 Washed; 15.0 Washed; 2.6 Washed
		Gallon	D1662F451; 5008	356	107*	69	99*	54	102	-	-	
			ET									
			2394C; EB	2469	390	67*	53	71.4*	81	109	-	
7	1967	210,000	TV600-32 (Polyurethane)									
		Gallon	2361C	2875	625	12	-	-	-	-	-	11.2 Non- Volatile
			2392C	2850	615	12.5	70.2	-	-	-	-	
			2394C	1950	460	51.3	64.2	-	-	-	-	
8	1968	10,000	Inside Poly 3175 (Polyurethane)									
		Gals	Outside Poly. 2475	585	-	-	-	-	-	91.35 24 Hrs	11 Non- Volatile	
			Outside " 1925	660	-	-	-	-	-	90.8 24 hrs		
			*95% Humidity	660	-	-	-	-	-	95.75 24 hrs	3.0 Stoved Gum	

TABLE 4 -- HISTORICAL DATA - PILLOW TANK COATED FABRICS

No.	Year	Size Gallons	Fabric	Cloth	Weight oz/yd ²	T. Ult W F	Tear W F	Puncture Lbs	Diffusion fl oz/ft ² 24 hrs	Tensile ζ 500 Hrs Weathering	Orie lbs/in	Adhesion % After 42 Days	Ref No.				
1	1979	20,000	Code N-908	Code 3640M	50.1	711 x 642	66 x 50	186	.046	84 x 81	48.8	39.6	53.8	29.5	55.9	1	
2	1979	10,000	N-3488 Gallons	Cure M-3 Nylon	46.7	506 x 509	38 x 39	113 x 128	.0063	-	-	19x18.6	-	-	-	2	
3	1978	3,000	H393 Gallons	M901 Coating	47.3	616 x 410 (150 x 350)	46 x 19 (25 x 25)	168	.0465	86.7 x 90	45 x 45	1041	621	91E	56E	3	
4	1978	80 x 80	82C39 1 inch Tube	RP-365 82C09 Kevlar D1666G609	38	1255 x 1267	62 x 66	311	.113	104 x 103	28	167	45	54	39	4	
5	1976	20x20 Pt Tube	80C39 D1666P514	RF-260 Nylon	44.72	589 x 559	25.6 x 21.3	196.4	.047	91 x 88.7	551	98	74	64	63	5	
6	1974	50,000	81C66 Gallons	D1662P451 2394C	3603M Nylon	30.2 Top 40.2 Bot.	672 x 714 705 x 676	56 x 42 56 x 49	189 185	.087 .091	89 x 86 80 x 081	28	71*	56	76*	66	6
7	1967	210,000	TV600-32 Gallons	2361C 2392C 2394C	3603M Nylon	28.5 Top 28.5 Bot.	683 x 671	30 x 32	163	.0178	100 x 98	27.7	49.5	87	-	-	7
8	1968	100,000	TV600 Gallons	-41	3602M Nylon	25.38	476 x 450	25 x 26	-	.02	-	15	-	-	-	8	

*95% Humidity

TABLE 5 -- HISTORICAL DATA - PILLOW TANK SEAM CHARACTERISTICS

No.	Year	Size	Seam Tensile Lbs./In End/Body	Tensile, Lbs./In		Slippage 50lbs./in @ 200°F-8Hrs	Orig Lbs/in	Adhesion % After 14 Days Water	% After 42 Days Water	Ref. No.	
				After 14 Days	After 42 Days						
1	1979	20,000 Gallons	719 514	E678 B434	732 456	699 389	794 None	59 57	97 -	41.7 -	
2	1979	10,000 Gallons	-	-	-	-	-	-	-	-	
3	1978	3,000 Gallons	388 350	E340 B325	395 391	-	-	180° None	-	-	
4	1978	80x80 In Tube	1192	E1010	924	1095	1106	None	35 E31* 121	103 71 76	54 -
5	1976	28x28 Ft. Tube	379	E386	400	446	493	None	66.7 -	84 -	-
6	1974	50,000 Gallons	E603 B504	661* 525*	656 427	564* 505*	560 420	None	51-42 31-37	111 59	68 54
7	1967	210,000 Gallons	647	532	532 (94 hrs)	-	-	-	-	-	-
8	1968	10,000 Gallons	-	-	-	-	-	-	-	-	8

*95% Humidity

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TABLE 6 -- HISTORICAL DATA - CHARACTERISTICS OF PILLOW TANK BONDED FITTINGS

No.	Year	Size	Alum/Fab		Tensile		After		Slippage		Adhesion		% After Water	% After Fuel	Ref No.
			Bond	Tensile Lb/in	After 14 Days	After 42 Days	Water	Fuel	50lbs/in@ 200°F-8Hrs	Orig 1bs/in	14 Days	42 Days			
1	1979	20,000 Gallons	951	830	521	788	448	None	51.5	101	53	95	50	1	
2	1979	10,000 Gallons	-	-	-	-	-	-	-	-	-	-	-	-	2
3	1978	3,000 Gallons	694 Avg	677	523	-	-	180°F None	-	-	-	-	-	-	3
4	1978	80x80 Inch Tube	1736	1855	1639	1366	1166	None	23	61	20	61	10	4	
5	1976	28 x 28 Ft Tube	807	760	905	432	415	None	62.5	71	44	66.7	52.5	5	
6	1974	50,000 Gallons	-	-	-	-	-	-	39.5	41.7	86	56	75	6	
7	1967	210,000 Gallons	-	-	-	-	-	-	-	-	-	-	-	-	7
8	1968	10,000 Gallons	-	-	-	-	-	-	-	-	-	-	-	-	8

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The approach used to calculate tank dimensions was to select the analytical method developed in Reference 9 for calculating tank heights and lengths for volumes of 5,000, 7,000, and 10,000 barrels with selected tank widths of 50, 60, and 68 (flat pattern),
Where: Volume = $3.1 \times L^{1.082} \times W^{1.204} \times (H^1)^{.773}$, gallons

Where H^1 = Tank Height, ft

W = Tank Width (flat), ft

L = Tank Length (flat), ft

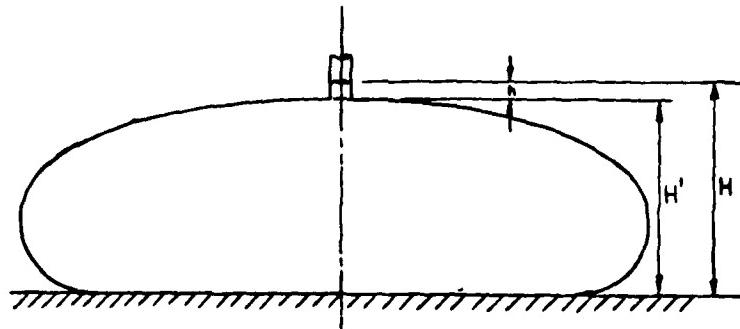
The tank fabric tension levels (T), percent fill(f), and standpipe heights(h) were calculated based on the methods developed in Reference 10,

$$\text{Tension, } T = \frac{\rho H^2 k^2}{4}, \text{ lbs/inch}$$

$$\text{Percent Fill, } f = \left(\frac{\text{cross-sectional area of tank}}{\text{cross-sectional area of circle with same perimeter,}} \right) \\ \text{i.e., } 2W = \pi D$$

Standpipe height, h = distance from top of fuel to top of tank, feet.

A sketch defining fuel height (H), tank height (H^1), and standpipe height (h) is presented below.



Curves of unit fabric weights versus ultimate quick break room temperature tension strengths were created using values for the materials' strength to weight ratios as cloth, estimated dip weights, coating weights to enclose the yarns and level the cloth and the weight of any additional coating to limit the rate of diffusion, Figure 1.

2. Tank Envelope Parameters

a. Historical Relationships

A listing of the values of the design parameters for past Pillow Tank envelopes is presented in Table 7. Tank volumes range from 3000 to 210,000 gallons (71 to 5,000 barrels). Long term operating seam tension values range from 11.3 to 55 lbs/inch which corresponds to fluid heights of 3.2 to 7.05 feet. The ratio of the quick-break room temperature tension strengths of the fabric range from 13 to 40 times the long term stress acting on the seams. This ratio or design factor (DF) has large values for the smaller tanks where operational factors limit minimum fabric strength selection and smaller DF values with the larger tanks where the seam strength values did govern the selection of material strengths.

The percent accuracy of calculating tank volume using the volume formula of Reference 9 is presented in the last column of Table 8.

b. Fabric Stress Vs. Fill Height

Maximum fabric tension is related to fill height (H) and the density of the fuel as follows:

$$\text{Tension, } T = \rho \frac{H^2 k^2}{4} = \text{const } H^2 k^2, \text{ lbs/inch, Reference 10.}$$

The parametric ratios of tank height to fuel height, H^1/H standpipe height to fuel height (h/H), fabric tension to fuel density \times tank diameter squared ($T/\rho D^2$), and fill ratio (f) can be presented versus H/D , Figure 2, where $\pi D = 2W$ or $D = \frac{2W}{\pi}$.

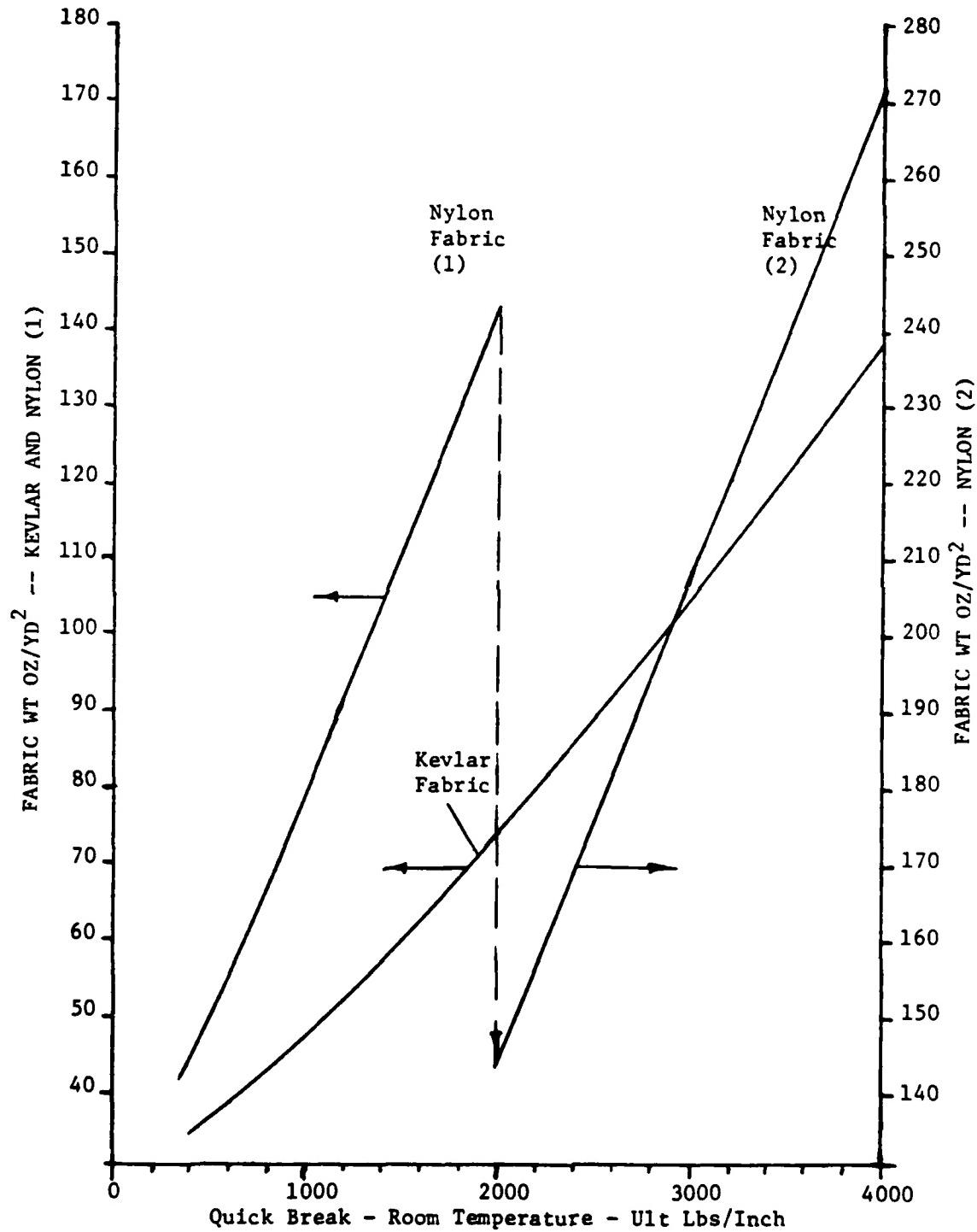


Figure 1 -- Fabric Unit Weights Versus Quick Break - Room Temperature Strengths (QB-RT Strengths)

TABLE 7 -- HISTORICAL DESIGN FACTORS RELATIVE TO QUICK-BREAK, ROOM TEMPERATURE STRENGTHS OF FABRIC CLOTHS

No.	Year	Size	Fabric Cloth	RT-QB Lb./In.	Wt., Oz./Yd. ²	Tank Height, Ft.	Fuel Height, Ft.	Tension, Lb./In $\rho = .03071 \text{ lb./in.}^3$	Design Factor Fabric Cloth QB/Tension
1	1979	20,000	3640N Gals Nylon	736X 694	9.58	5.54	5.653	35.3	20.8x19.7
2	1979 (1963)	10,000 12x44	3592N Gals Nylon	503X 484	7.5	3.76	4.043	18.1	27.8 x 26.7
3	1978	3,000 19-7X 10-2	3634N Gals Nylon	450X 450	8.0	3.06	3.2	11.3	(39.8x39.8)
4	1978	80x80 inch Tank	RF-365 Kevlar	1231X 1283	9.5	-	-	-	-
5	1976	23,200 28x28 ft	RF-260 Nylon	561X 588	10.1	5.73	5.807	37.26	15.1x15.8
6	1974	50,000 24x65	3603N Gals Nylon	713X 716	12.03	5.71	5.844	37.7	18.9x19.2
7	1967	210,000 48x96	3603N Gals Nylon	713X 716	12.03	7.0	7.05	55.0	13x13
8	1968	10,000 22x22	3602N Gals Nylon	450X 450	8.5	3.77	3.788	15.9	(28.3x28.3)

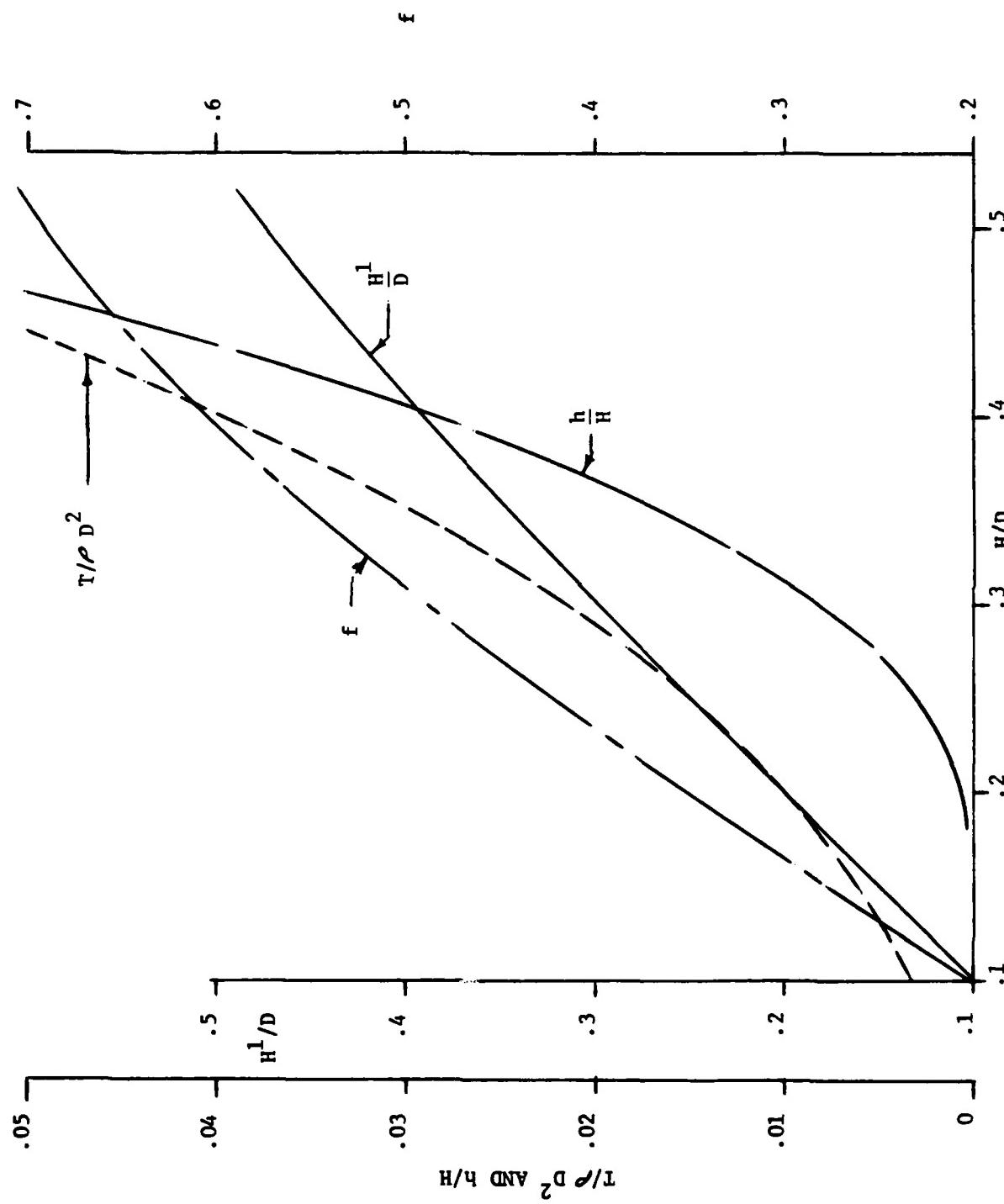
(Specification Minimum Values)

TABLE 8 -- COMPARISON OF CALCULATED AND MEASURED TANK VOLUMES

<u>Rated Tank Size Gallons & (Ft)</u>	<u>Height (H¹) Measured Tank, Ft</u>	<u>Width (W) Measured Flat, Ft.</u>	<u>Length (L) Measured, Flat, Ft.</u>	<u>Vol (1) Calculated Gallons</u>	<u>Vol Meas. Gals.</u>	<u>% Differential</u>
10,000 (22x22)	3.77	21.77	22.15	10,077	10,002	+.77
10,000 (12x44)	3.76	12.12	42.04	9,944	10,004	-.60
20,000 (24x28)	5.54	24.17	28.10	19,912	20,006	-.47
50,000 (24x65)	5.71	24.11	64.66	50,058	50,118	-.12
100,000 (24x123)	5.75	24 ⁽²⁾	123 ⁽²⁾	100,377	100,000 ⁽²⁾	+.38
210,000 (48x98)	7.0	48 ⁽²⁾	98 ⁽²⁾	210,544	210,000 ⁽²⁾	+.26

(1) Reference 9 Formula

(2) Nominal or Rated Values

FIGURE 2 -- FUEL TANK GEOMETRY AND TENSION PARAMETERS VERSUS H/D

The calculated tension parameter ($T/\rho D^2$) values for the different tank widths or diameters ($D = \frac{2W}{\pi}$) values increase rapidly as the total fuel height parameter (H/D) values are increased. The values of the ratio of the standpipe height to the fuel height only become significant for the larger values of H/D where the fabric tension values increase at a rapid rate with increasing values of H/D .

c. Surface Area Versus Fill Height or Fabric Tension for 5,000, 7,000 and 10,000 Barrel Tanks with Tank Widths of 50, 60, and 68 Feet

Total tank fabric area is related to tank widths (W) and lengths (L), for flat dimensions, for different tank heights (H^1) and tank volumes where the tank fabric area = $2WL$ and

$$\text{Volume} = 3.1 \times L^{1.082} \times W^{1.204} \times (H^1)^{.773}, \text{ gals, Ref 9.}$$

The calculated results are presented in Figure 3. The range of values for WL is 2000 to 10,000 square feet while the range of corresponding fabric tensions is 40 to 500 lbs/inch. Considering design factors of 10 and 20, the corresponding QB-RT fabric strengths range from 400 to 5000 and 800 to 10,000 lbs/inch, respectively.

If a fabric strength of at least 1000 lbs/inch is required to meet other fabric specification values, i.e., tension, tear and puncture, then tank heights of 7.0 and 9.7 feet ($T=50$ and 100 lbs/in) can be selected for DF=20 and 10, respectively. The WL values for 68 ft wide 10,000 barrel tanks of these heights are 8620 and 6780 square feet respectively. The 7.0 ft high tank has a flat area WL approximately the maximum size limit of 75 x 120 or 9000 sq ft for the tank.

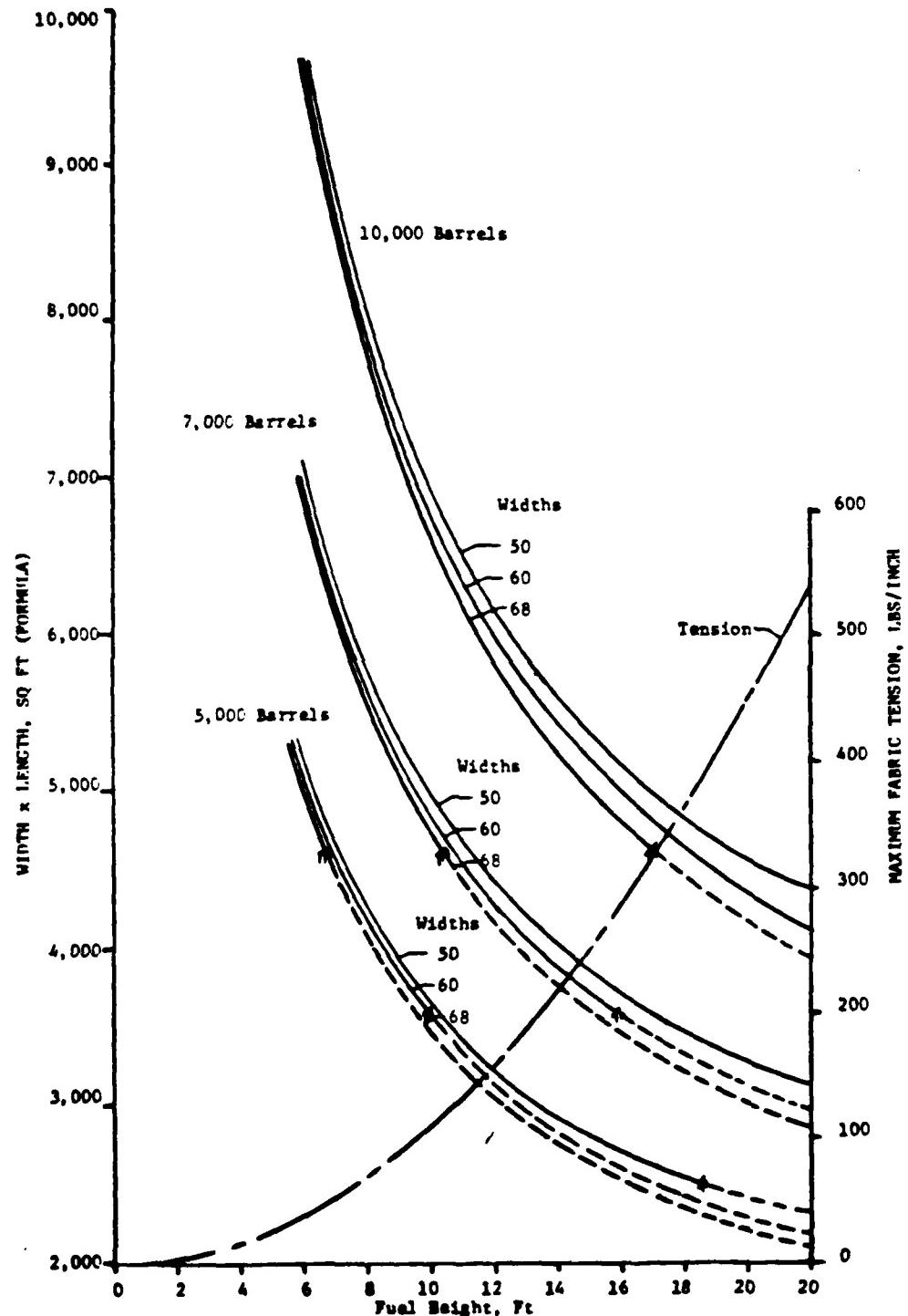


Figure 3 - Tank Width x Length Versus Fuel Height or Tensions for 10,000, 7000, and 5000 Barrel Tanks.

d. Calculation of Envelope Fabric Weights Vs. Tank Dimensions For Fabric Design Factors of 20 and 10 Times QB-RT Strength Values

The weights of the fabric for different size tanks were determined from the tensions associated with the fuel heights and associated tank heights and the corresponding tank flat areas (WL), figure 3 and the fabric weights versus fabric tensions presented in Figure 1 using design factors (DF) of 20 and 10 times the tensions for the QB-RT strength of the fabric. Fabric weights for 10,000, 7000, and 5000 barrel tanks using coated nylon fabric and a historical design factor of 20 are presented in Figure 4. The design goal of the fabric weighing less than 8000 pounds and the design requirement of the tank being less than 120 feet long are indicated by the hatched boundaries. It is obvious that 10,000 barrel tank lengths exceed the desired length value for fabric weights of less than 8000 pounds using historical design factors and fabric tensions. The broken portion of the curves indicate tank lengths that are less than tank widths and will lead to errors in the calculated results.

The 7000 barrel tank lengths fall within the boundaries using historical design factors and fabric seam tensions. For example, the weight of the fabric for a 60 ft wide by a 100 ft long 7000 barrel tank is approximately 7000 pounds with operating seam tension value between 50 and 60 lbs/in.

The 5000 barrel tank lengths and weights fall well within the boundaries. For example, the calculated weight of the fabric for a 60 ft wide by a 76 ft long tank is approximately 5000 pounds with a historical operating seam tension of 50 lbs/in. The tank length can be reduced to 60 ft, if an operating seam tension of 100 lbs/in is found to be acceptable. The fabric weight for this square tank is approximately 7300 pounds.

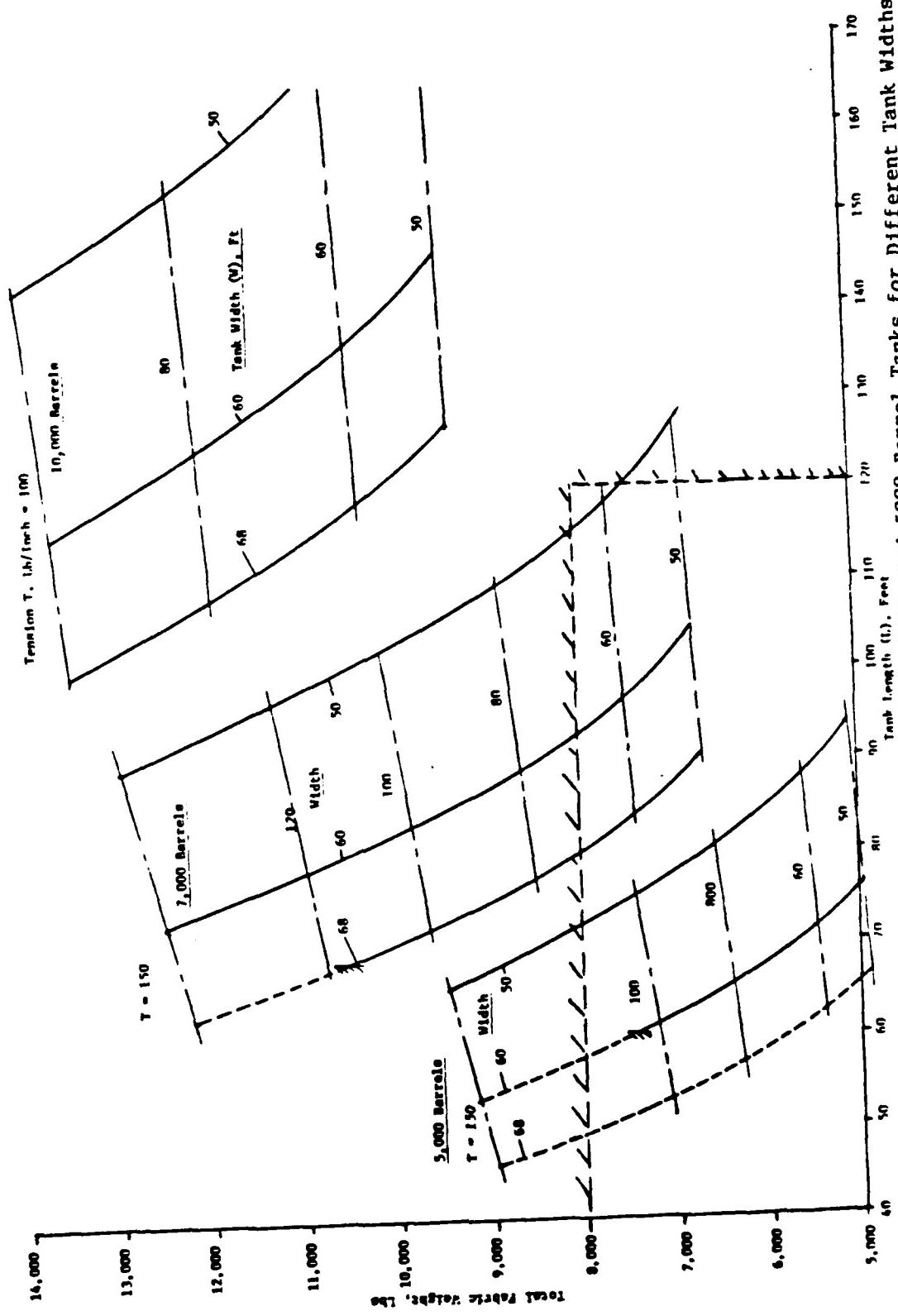


Figure 4 -- Total Fabric Weights of 10,000, 7000, and 5000 Barrel Tanks for Different Tank Widths and Fabric Tensions Versus Tank Lengths - Nylon Fabric Weights Using a Design Factor of 20.

The results from these calculations for the nylon fabrics indicate that the 7000 barrel tank is approximately the largest tank size within the boundaries using historical nylon fabric unit weights, design factors and operating seam tensions.

This same set of calculations were made using coated Kevlar fabric and a historical design factor of 20. The calculated results for the 10,000, 7000, and 5000 barrel tanks are presented in Figure 5. The same boundaries are indicated on the figure. The results indicate that a 10,000 barrel tank can be made within the length limits and the weight goals. However, tank dimensions of 68 ft wide by 120 ft long have to be selected to stay within historical operating seam tension values of 30-60 lbs/in. If a length of 100 ft is desired, the operating seam tension values must increase to 100 lbs/inch for the 68 ft wide tank.

The 7000 barrel tank lengths are well within the desired weight boundary and within the length boundary at historical operating seam tensions. The 60 ft wide by 100 ft long tank operates at a seam tension value between 50 and 60 lbs/inch and weights approximately 4200 pounds. Tank length can be reduced, if larger values of operating seam tensions are found to be acceptable, while being within the desired weight limits.

The 5000 barrel tank lengths and weights fall well within the boundaries. For example, the calculated fabric weight of a 60 ft wide by a 76 ft long tank is 3000 pounds with a historical operating seam tension of 50 lbs/in. If it is found to be acceptable to use larger operating seam tension values then shorter tanks can be selected while remaining within the desired fabric weight limits. For instance a 60 x 60 ft tank, operating at a seam tension value of approximately 100 lbs/in will weigh approximately 3700 pounds.

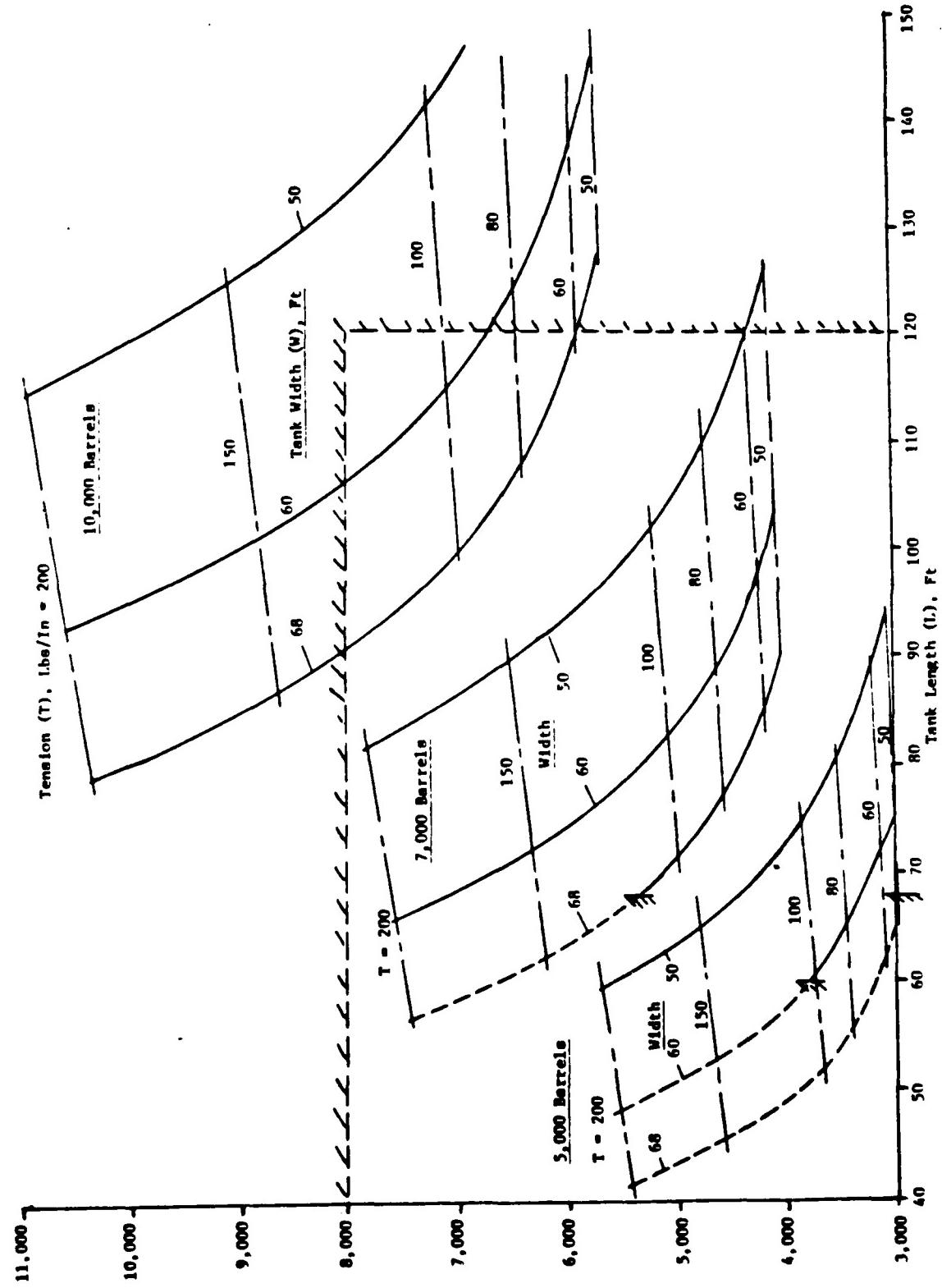


Figure 5 -- Total Fabric Weights of 10,000, 7000, and 5000 Barrel Tanks for Different Tank Widths and Fabric Tensions Versus Tank Lengths - Kevlar Fabric Weights Using a Design Factor of 20.

The results from these calculations for the Kevlar fabrics indicate that the 10,000 barrel size is just within the length limits at the 68 ft width with an operating seam tension value of 60 lbs/inch. If an operating seam tension value of 100 lbs/inch is found to be acceptable, tanks of 68 x 100 ft and 60 x 115 ft are possible within the desired weight limits.

The 7000 barrel Kevlar fabric tanks with the same dimensions and operating seam tensions as the nylon fabric tanks have less fabric weight, approximately 60 percent of the nylon fabric weight.

The 5000 barrel Kevlar fabric tanks are well within the boundaries and have reduced weights compared to the nylon tanks.

The effect of the value chosen for the design factor on the results of the calculations was investigated by choosing an arbitrary design factor of 10 instead of the historical 20 based on QB-RT strengths. To justify other than the historical value, data are required on the effect of the fluids on the seam strengths over long time periods.

As anticipated, using design factor values of 10 instead of 20 in the calculations, results in reduced nylon fabric weights so that a 68 ft wide tank is just within tank length limits at an operating seam strength of 60 lbs/inch, Figure 6. However, the associated fabric only has a QB-RT strength of 600 lbs/inch and will not meet some of the other fabric specifications, i.e., tear, tension, and puncture values. If an operating seam strength of 100 lbs/in is found to be acceptable, a tank 68 x 100 feet is possible within the weight limits and the fabric (1000 lbs/inch) can meet the other fabric specifications.

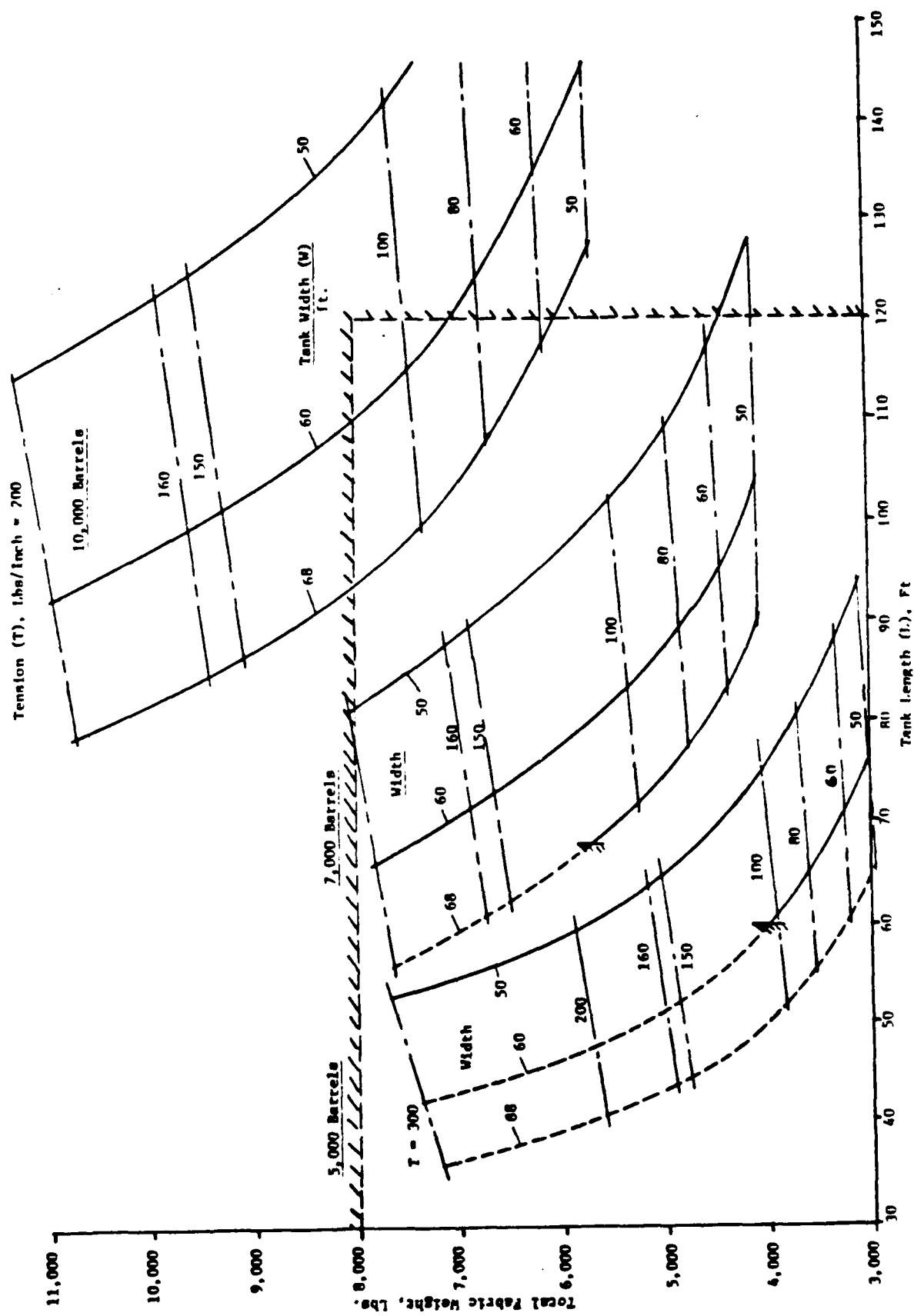


Figure 6 -- Total Fabric Weights of 10,000, 7000, and 5000 Barrel Tanks for different Tank Widths and Fabric Tensions Versus Tank Lengths - Nylon Fabric Weights Using a Design Factor of 10.

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The results from the calculations for the nylon fabric 7000 barrel tanks with a DF=10 indicate that tank fabric weights and lengths are well within the boundaries. Operating seam tension values of 100 lbs/in or greater are required if the fabric is to meet the other fabric specification values. Total fabric weights are considerably less than 8000 pounds for operating seam tensions of 100 lbs/inch, or even 150 lbs/inch.

The results from the calculations for the 5000 barrel tanks indicate the same trends with tanks weighing approximately 3000 lbs at historical operating seam tensions or approximately 4000 pounds using shorter tanks with an operating seam tension of approximately 100 lbs/in and 1000 lbs/in QB-RT fabric.

The use of coated Kevlar fabric and a design factor of 10 results in further reductions in the weight of the fabric for a given tank size, Figure 7. Again, to take advantage of lesser fabric weights, to obtain smaller tanks requires operating the seams at greater tensions than historical values. Weights of less than 5000 pounds are possible for the fabric of a 10,000 barrel Kevlar fabric tank, if operating seam tensions of 100 lbs/inch are found to be acceptable. The results for the 7000 barrel and 5000 barrel Kevlar fabric tanks indicate the same trends.

The same calculated values for tank dimensions and fabric weights presented in Figures 4, 5, 6, and 7 also are presented in tabular form for convenience, Table 9.

If reduced envelope weight is desired and if 1000 lb/in fabric is necessary to meet the other fabric specification values then the tank dimensions and envelope weights for design factors of 20 and 10 are the values listed in Table 10.

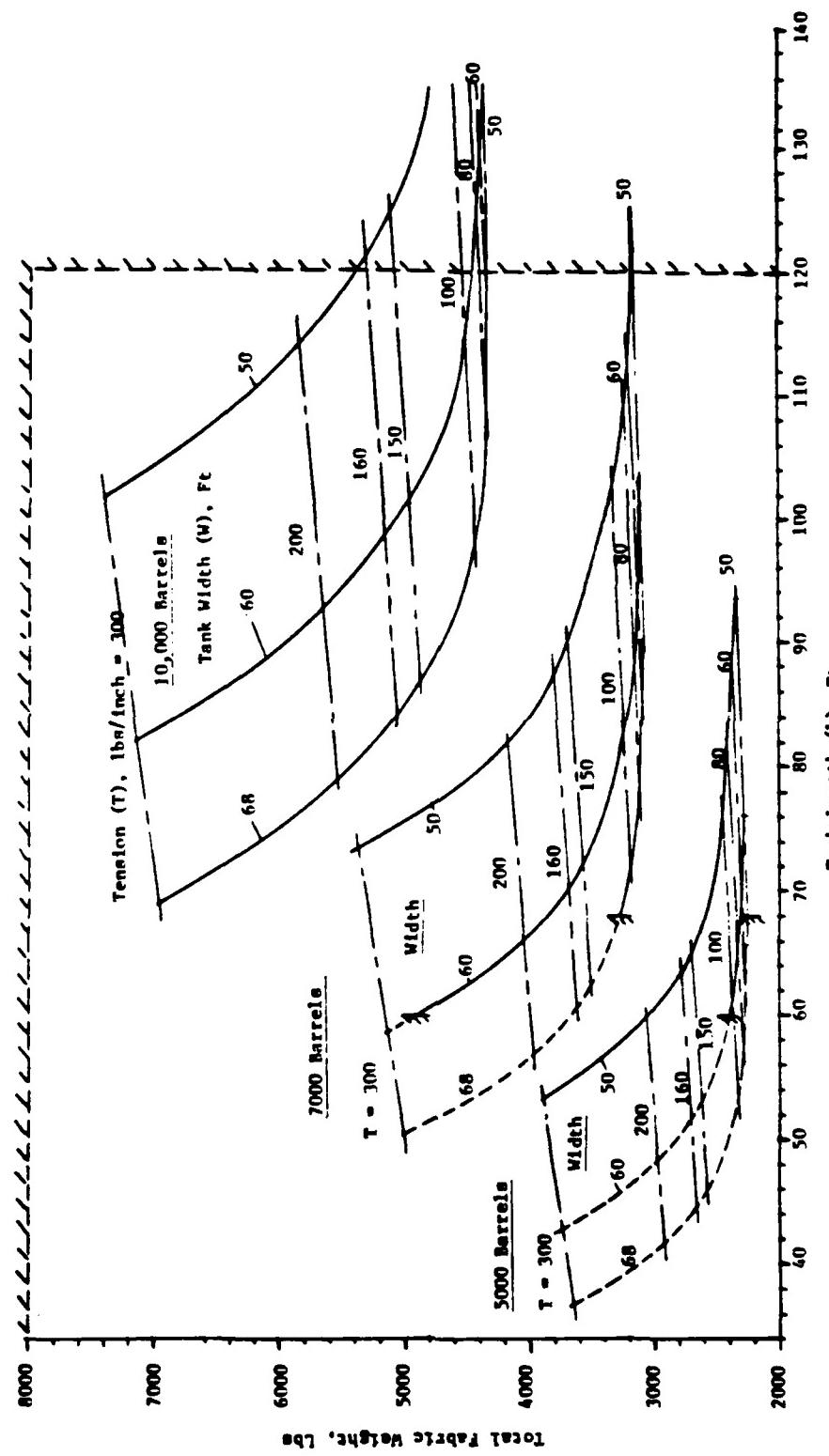


Figure 7 -- Total Fabric Weights of 10,000, 7000, and 5000 Barrel Tanks for Different Tank Widths and Fabric Tensions Versus Tank Lengths - Kevlar Fabric Weights Using a Design Factor of 10.

TABLE 9 - TOTAL FABRIC WEIGHTS FOR TANK VOLUMES, WIDTHS, AND FABRIC TENSIONS

Tank Volume	Tension Lb/in	Height Ft	Length Ft	50 Ft				60 Ft				68 Ft			
				Total Fabric Wt, Lbs		Kevlar	Length Ft	Total Fabric Wt, Lbs		Kevlar	Length Ft	Total Fabric Wt, Lbs		Kevlar	Length Ft
				Nylon	20DF			10DF	20DF			10DF	20DF		
Barrels	300	16.4	53.2	7684	3879	42.7	7401	3736	5520	41.5	5605	7190	3630	2900	5409
	200	13.6	59.6	5879	3042	5673	48	5720	2960	41.5	4906	44.4	2642		
	160	12.2	63.8	5184	2791	51.7	5041	2714	4638	45.6	4781	8958	2563	4522	
	150	11.8	65.2	5026	9418	2694	4754	53	4903	9187	7210	2395	51.9	3823	7009
	100	9.7	74.8	4052	7428	2467	3844	60.5	3933	3731	2354	3449	56.8	3540	6276
	80	8.7	80.8	3703	6565	2413	3535	65.7	3614	3254	5443	2308	62.1	3224	5392
Barrels	60	7.6	87.6	3346	5597	2373	3194	71	3254	3008	4940	2312	65.9	2956	4853
	50	7.0	93.4	3081	5059	2367	3081	76	3008	4940	2312	3008	2271	2956	
	300	16.4	73.4	10602	5352	58.7	10170	5133	50.3	9880	4049	7552	56.6	7647	3957
	200	13.6	81.4	8083	4183	7800	65.7	7825	4049	7552	6728	60.9	6728		3623
	160	12.2	87.6	7118	3833	70.7	6890	3710	62.1	6506	12509	6315	71.5	5265	12191
	150	11.8	89.4	6891	12913	3694	6519	72.2	5363	9831	3266	5088	76.8	5265	9652
A-26	100	9.7	102	5525	10129	3365	5242	82.5	4877	8645	3177	4655	76.8	4785	8482
	80	8.7	108.8	4987	8840	3249	4760	88.7	4877	8645	3174	4273	84.4	4385	7335
	60	7.6	119.6	4568	7641	3239	4360	97.7	4476	7488	3174	4273	84.4	4385	7335
	50	7.0	127.2	4195	6890	3224	4196	103.3	4090	6717	3143	4090	90.3	4051	6652
	300	16.4	101.4	14647	7394	81.8	14184	7160	69.3	13607	5693	10618	79	10665	6869
	200	13.6	114.2	11341	5869	10944	92.3	11003	5198	85.1	9409	86.6	9080	17016	5519
Barrels	160	12.2	122.2	9929	5346	99	9653	9327	17478	5000	8828	4552	7092	99.7	10293
	150	11.8	124.4	9589	17969	5140	9071	100.8	7475	13704	4425	6484	107.5	7345	13466
	100	9.7	141.6	7670	14061	4671	7277	115	6793	12041	4431	5965	118.8	6700	11879
	80	8.7	152.2	6976	12366	4545	6659	123.5	6103	136.3	6249	10452	118.8	6172	10324
	60	7.6	167.4	6394	10695	4334	5845	9598	4492	5753	145.3	4447	5753	5687	9338
	50	7.0	177.2	5845	9598	4492	5845	145.3	5753	9447	4421	5753	126.8	4370	5687

TABLE 10 — TOTAL FABRIC WEIGHTS AND TANK LENGTHS USING 1000 POUND PER INCH FABRIC
AND DESIGN FACTORS OF 10 AND 20 FOR THREE TANK WIDTHS

Tank Volume	Tank Width, Ft	Total Fabric Weights, Lbs			Tank Length, Ft	
		10DF	20DF	Nylon	10DF	20DF
5000 Barrels	50	4052	5059	2467	3081	74.8
	60	3933	4940	2395	3008	60.5
	68	3823	4853	2328	2956	51.9
7000 Barrels	50	5525	6890	3365	4196	102
	60	5363	6717	3266	4090	82.5
	68	5265	6652	3206	4051	71.5
10,000 Barrels	50	7670	9598	4671	5845	141.6
	60	7475	9447	4552	5753	115
	68	7345	9338	4473	5687	99.7

e. Effect of Adding Ten Percent More Fuel Than the Design Value on Tank Fabric Tensions

Adding ten percent more fuel to a given tank design increases the fuel height and the tank stress level. The new tank height H^1 can be calculated using the volume formula. The total fuel height H , can be determined from the H^1/D values and the corresponding values of H/D , Figure 2.

The increases in fabric stresses for the 7000 barrel tank are listed in Table 11 for tanks designed with normal operating seam tensions of 50 thru 150 lbs/inch.

3. Fitting Strength

A preliminary examination of the aluminum fittings required in the container indicates that those presently used in fuel containers are sufficiently strong to accept the fabric loads anticipated in the 7000 barrel tank. No further stress analysis is required on the fittings until a final tank configuration is proposed. A more rigorous analysis of fitting strength will be made when the final design configuration is selected in the trade-off study (Task 5).

4. Summary of Results from Tank Sizing Analyses

The tank sizing studies indicate that:

- a. The two goals of low tank weights for transportation and handling and of occupying a minimum of ground area, i.e., minimum lengths and widths for a given volume are in opposition to each other. If a minimum of occupied ground area is desired, smaller tank sizes are constrained by tank weight limits or by the state-of-the-art of the strength of seams. If minimum tank weight is desired, then larger tank ground sizes are constrained by the dimensional limits or the need for the fabric to meet more than just the operating tension requirements.

TABLE 11 -- 7000 BARREL TANK FILLED TO 7700 BARRELS

Tension With 7000 Barrels, Lbs/In	Common Width	Length	New Values With 7700 Barrels				
			Tank Height H, Ft	Fuel Height, Ft	Fabric Tension Lb/In	Increase ΔT, Lb/In	Tension Increase, %
150	50	89.4	13.015	13.473	200.6	53.6	33.7
100	50	102	10.822	10.987	133.4	33.4	33.4
80	50	108.8	9.887	9.987	110.2	30.2	37.8
60	50	119.6	8.661	8.705	83.8	23.8	39.6
50	50	127.2	7.945	7.96	70.0	20.0	40.0
150	60	72.2	13.225	13.446	199.80	49.8	33.2
100	60	82.5	10.973	11.046	134.85	34.85	34.9
80	60	88.7	9.915	9.945	109.40	29.4	36.8
60	60	97.7	8.661	8.673	83.13	23.13	38.6
50	60	103.3	8.01	8.018	71.05	21.05	42.1
150	68	62.1*	13.427	13.560	203.2	53.2*	35.5*
100	68	71.5	11.022	11.055	135.1	35.1	35.1
80	68	76.8	9.972	9.988	110.3	30.3	37.8
60	68	84.4	8.739	8.742	84.5	24.5	40.8
50	68	90.3	7.950	7.953	69.90	19.9	39.8

*Length less than width.

- b. The range of possible tank sizes and weights are presented in Table 12, considering goals of minimum ground area, weights less than 10,000 lbs total (approximately 8,000 lbs of fabric), fabric strength minimums of 1000 lbs/inch and a maximum operating tension limit of 200 lbs/inch for 7000 barrel tanks.

The results from the nylon tank calculations indicate that minimum tank ground areas are possible within the 8,000 lb weight limits if a 200 lbs/inch operating fabric tension is possible with a DF=10. Minimum tank weights are possible within constraints if a 100 lbs/inch and 50 lbs/inch are possible for DF=10 and 20, respectively. It is interesting to note that at a DF=20 the minimum ground area and minimum weight tank are the same tank for a 50 ft wide tank.

The results from the Kevlar tank calculations indicate that minimum tank ground areas are possible within the weight limits if a 200 lbs/inch operating fabric tension is possible with DF=10 and 20. Minimum tank weights are possible within constraints if 100 lbs/inch and 50 lbs/inch are possible for DF=10 and 20 respectively. The Kevlar tanks show a weight advantage over the nylon tanks for DF=10, but no size advantage because of tension constraints. At a DF=20 the Kevlar tanks show a size and weight advantage over the nylon tanks.

- c. Design factors are referenced to the quick-break room temperature strengths of the cloth. The factors appear large, however, the effect of long term static loadings, and environmental factors (ultra-violet, water/fuel) acting on the cloth, coating, and seams reduces the actual operating margins to much lower values.
- d. Figure 3 shows that ground area is minimized as tank width increases. This is because storage of fuel in collapsible tanks becomes more efficient as tanks approach a rectangular configuration.

TABLE 12 -- POSSIBLE 7000 BARREL TANK SIZES AND WEIGHTS CONSIDERING DESIGN GOALS AND CONSTRAINTS

Material Type	Tank Width, Ft.	Minimum Ground Area With An Approximately 8000 Lb Fabric Weight Limit						Minimum Fabric Weight With A 75 x 120 Ground Dimensional Unit					
		DF=10			DF=20			DF=10			DF=20		
		Tension Lbs./In	L, Ft	Wt., Lbs	Tension Lbs./In	L, Ft	Wt., Lbs	Tension Lbs./In	L, Ft	Wt., Lbs	Tension Lbs./In	L, Ft	Wt., Lbs
Nylon	50	200	81.4	8083	60	119.6	7641	100	102	5525	60	119.6	7641
	60	200	65.7	7825	60	119.6	7488	100	82.5	5363	50	103.3	6717
Kevlar	68	200	56.6	7647	80	76.8	8482	100	71.5	5265	50	90.3	6652
	50	200	81.4	4183	200	81.4	7800	100	102	3365	60	119.6	4360
Kevlar	60	200	65.7	4049	200	65.7	7552	100	82.5	3266	50	103.3	4090
	68	200	56.6	3957	200	56.6	7379	100	71.5	3206	50	90.3	4051

D. Review of the State-of-the-Art of Fabrication Techniques - Task 2

1. Discussion

The generally accepted state-of-the-art methods of fabricating collapsible Fuel Storage Containers have been; (1) to utilize roll good materials that are machine coated, which are then cut, seamed, and vulcanized into a finished product. In this approach the vulcanization may be accomplished by placing the complete product in an autoclave if the roll goods are uncured or the seaming of the cured roll good patterns may be accomplished under heat and pressure in a seaming press. (2) another method is a urethane spray approach which utilizes a chemical vulcanization process where tank sections are assembled from uncoated cloth using a urethane compound in the seam following which the assembled units are spray coated with urethane elastomer.

In the cured roll goods approach, using a seaming press, the elastomers are generally either nitrile or polyurethane compounded for excellent fuel and weathering resistance.

2. Conclusions

The state-of-the-art manufacturing methods as they relate to a 7,000 bbl or larger Fuel Storage Container are limited to two (2) approaches due to weight and size of the proposed tank. One approach is to fabricate the container by the urethane spray method and the second is to utilize cured fabric patterns and then seam the patterns into a finished product using a seaming press. Autoclave curing methods are not feasible for products of this size and weight.

In order to minimize handling problems in the seam press the tank should be built in sections and then seamed together. This will reduce handling the total weight of the tank until the final assembly operation.

We do not, at this time, foresee any other material handling problems in the fabrication of a 7,000 bbl tank.

E. Select Candidate Materials - Task 3

1. Introduction

The overall purpose of this effort is to select leading candidate state-of-the-art materials which have the greatest potential for satisfying the design requirements for the 7,000 barrel tank.

The physical properties of various coating compounds, fabric types, and fabric weaves were evaluated separately and leading candidates selected. Following this an evaluation was made of the potential structural integrity of coated fabrics made from each combination of leading coating compound and fabric along with their potential for making structurally adequate seams and potential for bonding to aluminum fittings.

2. Analytical Approach

Each materials potential for satisfying the design objectives was evaluated using a system of physical property weighting factors and material property ranking factors. A weighting factor was assigned to each physical property being considered based upon its relative importance to providing a material which would make an acceptable fuel container. The weighting factors were assigned qualitatively based upon our experience in this product area and knowledge of fuel container design requirements. Physical properties of major importance were assigned weighting factors greater than "1", and minor physical properties were assigned weighting factors of less than "1". A physical property assigned a ranking factor of "2" would be judged to be twice as important as one assigned a weighting factor of "1".

A ranking factor was then assigned to each physical property of each candidate material being considered based upon its potential for meeting the design requirement as specified in the experimental purchase description for the 7,000 barrel tank or by comparing its performance to the most common state-of-the-art material under consideration. A ranking factor of "1" is considered to be state-

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of-the-art. If a material exhibited a property poorer than the state-of-the-art it would be assigned a ranking factor of less than "1". If it exhibited a property better than the state-of-the-art it would be assigned a ranking factor greater than "1". We attempted to assign ranking factors as ratios to state-of-the-art physical properties where ever possible in order to quantify the result. However, in many cases there was not enough existing data to do this. In these instances a ranking factor of less than "1" was assigned since absence of data indicates a measure of risk.

The ranking factor for each material property was then multiplied by the corresponding weighting factor assigned to that property to obtain a weighted-ranking factor for each physical property being considered for each material. The sum of these weighted-ranking factors for a particular material then represents its potential for satisfying the design requirement or shows where it stands relative to the state-of-the-art. The material with the largest weighted-ranking factor sum will be the material most likely to produce an acceptable tank.

3. Selection of Candidate Coating Compounds

a. General

There are many elastomers which could be considered in this state-of-the-art study. However, many compounds have properties which eliminate them from consideration.

EPDM, natural rubber, butyl and SBR are known to have poor resistance to hydrocarbon fuels. Since these elastomers would not be candidates for use in the tank, no effort is made to assign numerical ratings for various properties. The data in Table 13, taken from company files illustrates the very poor strength of these elastomers after exposure to Type II fuel. Tests on two separate formulations of each elastomer are shown.

Viton fluoroelastomer exhibits resistance to hydrocarbon fuels. However, Viton's price of \$12.00 a pound makes its use imprudent for applications where other elastomers can be used. For this

TABLE 13 -- TYPICAL FUEL RESISTANCE OF BUTYL, STYRENE-BUTADIENE,
ETHYLENE PROPYLENE DIMER AND NATURAL RUBBERSButyl

Original	Tensile	2000
	Elongation	640
96 Hrs	Tensile	350
R.T. Type II	Elongation	140
Original	Tensile	2050
	Elongation	675
14 Days	Tensile	200
160°F Type II	Elongation	110

SBR

Original	Tensile	2400
	Elongation	530
96 Hrs	Tensile	200
R.T. Type II	Elongation	90
Original	Tensile	2850
	Elongation	610
72 Hrs	Tensile	150
R.T. Type II	Elongation	90

EPDM

Original	Tensile	2075
	Elongation	480
14 Days	Tensile	700
160°F Type II	Elongation	130
Original	Tensile	1750
	Elongation	430
96 Hrs	Tensile	600
R.T. Type II	Elongation	100

Natural Rubber

Original	Tensile	3750
	Elongation	525
96 Hrs	Tensile	400
R.T. Type II	Elongation	100
Original	Tensile	4100
	Elongation	560
96 Hrs	Tensile	350
R.T. Type II	Elongation	100

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reason, Viton is not considered a candidate coating for the tank and no numerical ratings are given for its various properties.

The following elastomers are those recommended and used in applications where there is contact with hydrocarbon fuels:

Polysulfide
Chloroprene (Neoprene)
Epichlorohydrin Copolymer
Nitrile
Urethane

b. Weighting Factors of Physical Properties to be Considered

1) Tensile Strength

Due to the proposed tank being larger and operating at higher loads than current tanks, strength of the coating is felt to be an especially critical parameter and is assigned as weighting factor of 2.

2) Elongation

This is a major parameter for a flexible rubberized fabric product. With less than 300% original elongation the fabric coating might not stretch adequately during creasing and folding, particularly after reduction from the initial value due to aging. This property is therefore assigned a weighting factor of "1".

3) Modulus

A lower modulus coating will make a more flexible fabric, all other factors being equal. This property does not influence performance and so is considered a minor parameter. It is therefore assigned a weighting factor of .5.

4) Fuel Resistance

The purpose of the tank is to securely hold fuel. Thus strength of the tank components after exposure to fuel is the single most critical parameter and is assigned a weighting factor of "3".

Note that due to the identification of benzene as a carcinogen, there have been product specification changes from Type II Fuel to ASTM Fuel D, and there now is a change in the Type II Fuel specification to remove benzene. None of these changes effect test results, and information obtained on old Type II, New Type II, and ASTM Fuel D can be used in an interchangeable manner.

5) Moisture Resistance

Tanks can be exposed to ground water in the berm in which they are installed, and minute amounts of water may also be found in the fuel stored in them. This physical property measures the resistance of candidate coatings to hydrolysis. This property is considered to be of major importance and is assigned a weighting factor of "1".

6) Resistance Weathering

This is a major parameter since the degree of resistance to radiation will substantially influence service life. It is therefore assigned a weighting factor of "1".

7) The volume of fuel in a tank is so large compared to the amount of tank coating compound that it is in contact with that fuel purity is virtually unaffected during storage. This property is therefore assigned a weighting factor of .5.

It also should be noted that while a value of 20 mg/100 ml is the goal value, specifications for aircraft fuel cells and 3,000 and 10,000 gallon collapsible fabric tanks call for 60 mg/100 ml, and that these products are used with no problems from coating contamination.

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c. Ranking Factor for Candidate Coating Compounds

The Ratings for Parameters for these coatings are given in Table 14.

1) Polysulfide

Polysulfide elastomers are excellent in resistance to hydrocarbon fuels, but have low tensile strengths. The ratings for tensile, elongation, and 200% modulus are based on information from Thiokol Chemical Corporation (Ref 11). The ratings for loss after water and fuel soaks are projections from Thiokol Chemical Corporation (Ref 12). Weathering and Type II fuel contamination are unknown but probably suitable since polysulfide elastomers are used as sealants in exterior applications and as linings in metal aircraft fuel tanks.

2) Epichlorohydrin Copolymer

Epichlorohydrin copolymer has been investigated as a coating for collapsible fuel storage tanks. The data used in assigning ranking factors is shown in Table 15 which was taken from a report by the Firestone Tire & Rubber Company (Ref 13). Generally, Epichlorohydrogen capolymer has physical properties similar to those traditionally used in collapsible tanks but offers improved resistance to hydrolysis.

3) Chloroprene

Chloroprene (Neoprene) is used as a coating for hoses which are used in transporting hydrocarbon fuels. However, the loss in tensile strength of chloroprene in Type II fuel is considerable, as shown by the data in Table 16. Chloroprene should offer improved resistance to moisture, but may also contaminate stored fuel slightly more than traditional coatings.

TABLE 14 -- COATINGS FOR TEXTILES - STATE OF ART

<u>Weighting Factor, W</u>	<u>Ranking Factor (R)</u>	<u>Initial Tensile Strength</u>		<u>Ultimate Elongation</u>		<u>Modulus, psi @ 200% Elongation</u>		<u>Water Modulus</u>		<u>Fuel</u>		<u>Weathering Resistance</u>		<u>Fuel Contamination</u>		<u>Sum of Weighted Factor</u>	
		2	1	1	.5	1	RW	R	RW	R	RW	R	RW	R	RW	R	.5
<u>Coating compound</u>																	
Nitrile	(1)	2	(1)	1	(1)	.5	(1.5)	1.5	(1)	3	(1)	1	(1)	1	(1)	.5	9.50
Urethane	(1)	2	(1)	1	(.5)	.25	(1)	1	(1)	3	(1)	1	(1)	1	(1)	.5	8.75
Polysulfide	(.5)	1	(1)	1	(1)	.5	(1)	1	(1)	3	(1)	1	(1)	1	(1)	.5	8.00
Chloroprene	(1)	2	(1)	1	(1)	.5	(1.5)	1.5	(.5)	1.5	(1)	1	(.5)	1	(.5)	.25	6.75
Epichlorohydrin Copolymer	(1)	2	(1)	1	(1)	.5	(1.5)	1.5	(1)	3	(1)	1	(1)	1	(1)	.5	9.50

TABLE 15 -- PHYSICAL PROPERTIES OF EXPERIMENTAL
EPICHLOROHYDRIN COPOLYMER TANK
COATING COMPOUND, REF 13

PROPERTIES

Initial

Tensile Strength, psi min	1300-1700	
Stress at 200% Elongation	400-550	
Ultimate Elongation, % Min	600-800	

Properties After Immersion in Type II
Fuel @ 160°F

14 Days 70 Days

Volume Change, %	11	8
Initial Tensile Strength, % Retained (Interior/Exterior Compound)	63	56

Properties After Immersion in
Distilled Water @ 160°F

Volume Change, %	6	4
Initial Tensile Strength, % Retained (Interior/Exterior Compound)	125	79

Properties After Accelerated Weathering
for 500 hrs at 10% Elongation

Initial Tensile Strength, % Retained	96
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TABLE 16 -- TYPICAL PHYSICAL PROPERTIES OF CHLOROPRENE ELASTOMERS
AFTER EXPOSURE TO FUEL AND WATER

Original	300% Modulus	1300
	Tensile	2575
	Elong	575
14 Days	Tensile	2450
160°F Water	% Ret	95
	Elong	415
14 Days	Tensile	500
160°F Type II	% Ret	19
	Elong	300
Original	300% Mod	1500
	Tensile	2175
	Elong	445
14 Days	Tensile	1500
160°F Water	% Ret	69
	Elong	200
14 Days	Tensile	450
160°F Type II	% Ret	21
	Elong	235
Original	Tensile	2175
	Elong	450
7 Days	Tensile	675
R T Type II	% Ret	31
	Elong	140

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4) Nitrile

Nitrile rubber has a long history of use in collapsible fuel storage containers. Table 17 shows the properties of a nitrile rubber compound suitable for use in a collapsible tank. This data was obtained in qualification testing of tanks for Goodyear's most recent military collapsible tanks order, Ref 1, where a nitrile rubber coating was supplied.

5) Urethane

Urethane coatings are commonly used in collapsible fuel storage containers. A wide variety of urethane fabric coatings are available, some of which are suitable for use in collapsible fuel storage containers, and some not.

Urethane coatings can be either thermoplastic or thermo-setting, or have intermediate characteristics. Polyols of either polyester or polyether type are normally used in conjunction with various isocyanates, diamines and diols or triols.

Urethane elastomers have been subjected to failure due to hydrolysis. This deficiency has been recognized, and improved urethanes have been developed.

The urethane coatings believed to be most suitable for collapsible fuel storage tanks, were used by Goodyear to fabricate experimental aramid and nylon reinforced tanks for the Army, Ref 4&5. The ratings for urethane are based on the information contained in the final reports on these projects and the data shown in Table 18 shows the physical properties of these polyurethanes.

TABLE 17
CHARACTERISTICS OF NITRILE COATING COMPOUNDS, Ref 1

PROPERTY	FED-STD-191 & ASTM TEST METHOD	MIL-T-82123A (MC) PARAGRAPH	REQUIREMENT	ACTUAL DATA
Tensile Strength (Initial)	ASTM-D412		1500 lbs/in ² (Min)	1827
Ultimate Elongation	ASTM-D412		300% (Min)	545
Tensile Strength after Immersion in distilled water @ 160° F -2° F for the following durations				
14 Days	6111		40% of Initial	95.2%
42 Days	6111		25% of Initial	106.4%
Tensile Strength After fuel immersion in test fluid (2) at 160° F -2° F for the following duration				
14 Days	6001/6111		40% of Initial	74.6%
42 Days	6001/6111		25% of Initial	74.6%
Resistance to light after 500 hours accelerated weathering @ 10% elongation (3)		ASTM-D750 (3)	65% of Initial Tensile Retained	92.0%
Fuel Contamination: (5) Unwashed existent gum				
Heptane washed existent gum			4.6.8	12.6
			4.6.8	5 MG/100 ML
				0.1

NOTES: 1. Properties after cure.

2. Medium shall consist of 60% Medium No. 4, 25% Medium No. 8, and 15% Medium No. 9 per FED-STD-601.

Test Method No. 6001.

3. Alternate Corex D filters in place.

4. Applicable to all exterior compounds, ie, compounds between the nylon cloth and the outside of the tank.

5. Applicable to all interior compounds, ie, compounds between the nylon cloth and the inside of the tank.

TABLE 18
PROPERTIES OF SPRAYED POLYURETHANE COATING COMPOUNDS

<u>Physical Properties</u>	<u>Test Method</u>	<u>Requirements</u>		<u>Actual Data</u>	
<u>Initial</u>					
Tensile Strength					
a. B2C39 ⁽²⁾	FTMS-601, 4111	4000 (min)		3277	
b. D1666F609 ⁽³⁾		3000 (min)		3349	
c. B2C09 ⁽³⁾		2000 (min)		2160	
Stress at 200% Elongation	FTMS-601, 4131				
a. B2C39 ⁽²⁾		1500 (max)		1174	
b. D1666F609 ⁽³⁾		1500 (max)		1160	
c. B2C09 ⁽³⁾		750 (max)		1189	
Ultimate Elongation	FTMS-601, 4121				
a. B2C39 ⁽²⁾		300 (min)		410	
b. D1666F609 ⁽³⁾		300 (min)		440	
c. B2C09 ⁽³⁾		300 (min)		340	
After Immersion In Distilled Water (ph 7.0 ±0.2) at 160°F ±20					
Volume Change	FTMS-601, 6211	<u>14 Days</u>	<u>70 Days</u>	<u>14 Days</u>	<u>70 Days</u>
a. B2C39 ⁽²⁾		Record	Record	1.6	1.7
b. D1666F609 ⁽³⁾		Record	Record	2.2	2.4
c. B2C09 ⁽³⁾		Record	Record	1.2	1.0
Initial Tensile Strength Retained	FTMS-601, 6111 Para. 4.8.1				
a. B2C39 ⁽²⁾		60	40 (min)	94/3075	82/2697
b. D1666F609 ⁽³⁾		60	40 (min)	107/3596	93/3118
c. B2C09 ⁽³⁾		50	25 (min)	77/1667	89/1914
After Immersion In Medium #5 at 160° ±20		<u>14 Days</u>	<u>70 Days</u>	<u>14 Days</u>	<u>70 Days</u>
Volume Change	FTMS-601, 6211				
a. B2C39 ⁽²⁾		Record	Record	59.3	71.5
b. D1666F609 ⁽³⁾		Record	Record	52.1	63.0
c. B2C09 ⁽³⁾		Record	Record	80.4	94.1
Initial Tensile Strength Retained	FTMS-601, 6111 Para. 4.8.1				
a. B2C39 ⁽²⁾		40	30 (min)	53/1740	48/1581
b. D1666F609 ⁽³⁾		40	30 (min)	51/1696	48/1624
c. B2C09 ⁽³⁾		35	25 (min)	58/1261	51/1117
After Accelerated Weathering for 500 hours (4)	FTMS-191, 7311				
Initial Tensile Strength Retained	FTMS-601, 6111 Para. 4.8.1				
a. D1666F609 ⁽³⁾		75 (min)		92/3081	
b. B2C09 ⁽³⁾		75 (min)		91/1966	
Fuel Contamination	ASTM D381-70				
Unwashed Existent Gum	ASTM D381-70 Para. 9.1 - 9.6				
B2C39 ⁽²⁾ MG/100AAL		20 (max)		20.7	
Heptane Washed Existent Gum	ASTM D381-70 Para. 9.8-9.12				
B2C39 ⁽²⁾ MG/100AAL		5 (max)		7.25	

TABLE 18 (continued)

NOTES:

- (1) The percentage tensile strength retained is:
Tensile strength retained after immersion or weathering x 100
Initial tensile strength value actually obtained (average of 3 or more samples)
- (2) Interior compounds: All compounds between the Kevlar cloth and the inside of the tank. 82C39 (Polyester, Black)
- (3) Exterior compounds: All compounds between the Kevlar cloth and the outside of the tank. D166GG609 (Polyester, Tan) 82C09 (Polyester, Tan)
- (4) Exposed at 10% elongation with alternate Corex D filters in place.

d. Selection of Coatings

The Table 14 cumulative numerical ratings rate nitrile and epichlorohydrin copolymer highest followed by urethane.

It is recommended that nitrile and urethane be the coatings considered for the 7,000 barrel collapsible fuel storage container.

Nitrile is recommended on the basis of its top numerical rating and on the basis of its history of successful use in collapsible tanks.

Epichlorohydrin copolymer has as high a numerical rating as nitrile, but is not recommended. The final report on the development of this material (Ref 14) calls for considerable follow on sample work and does not recommend an experimental tank be built. We have an indication that an epichlorohydrin copolymer flexible tank may have been built, but have not been able to confirm this fact. All available information indicates the use of epichlorohydrin copolymer in a 7000 barrel collapsible fuel storage container would not be using state-of-the-art technology.

Urethane is recommended on the basis of its high numerical rating and on the basis of the successful use of some urethane coated collapsible tanks. In particular, it is felt that urethanes which pass both the 70 day fuel and 70 day water tests called for in the purchase description, will be suitable for use on the 7,000 barrel tanks. It is also felt that urethanes of the cureable or thermosetting type would be more suitable than those of the thermoplastic type. Thermoplastic materials are inherently subject to creep if subjected to sufficient long term constant stress.

4. Selection of Candidate Fabrics

a. General

The fabrics which will be considered in this study are nylon, aramid, polyester and fiberglass. Metal fibers are too heavy, and carbon and other exotic new fibers are too expensive to be considered. The general properties of the fabrics under consideration are shown in Table 19. This data is a compilation of data from Ref 15 through 18.

b. Weighting Factors of Physical Properties to be Considered

1) Tensile Strength

The tensile strength of the fabric selected is one of the most important physical properties to be considered. However, since we are also interested in minimizing the weight of the tank being developed, the physical property which will be considered is specific tensile strength, that is, tensile strength per pound of material. This physical property will be assigned a weighting factor of "3".

2) Fuel Resistance

The fabric selected must be resistant to the affects of continuous exposure to fuel. This property will be evaluated by considering the ability of a candidate fabric to resist degradation of its tensile strength when exposed to fuel and will be assigned a weighting factor of "3" since it is also a major parameter for consideration.

3) Water Resistance

The reinforcing fabric may also come into contact with moisture from ground water or small amounts of moisture in the fuel, and should resist this exposure. This property will also be evaluated by considering the ability of a candidate fabric to resist degradation of its tensile

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TABLE 19 - General Physical Properties of Candidate Reinforcing Materials

<u>Physical Property</u>	<u>Nylon</u>	<u>Polyester</u>	<u>Aramid</u>	<u>Fiberglass</u>	<u>Ref</u>
Yarn Tenacity, gm/denier	8	6-8	22	9.6	15
Specific Gravity	1.14	1.38	1.44	2.5	15,16
Elongation, Ult, %	16-18	12-16	4.0	3.1	15
Modulus, gm/denier	55	105	480	310	18
UV Resistance	P	G	P	E	17,18
Fuel Resistance	E	E	E	E	15
Moisture Resistance	G	G	E	E	15
Coating Adhesion	E	F	F	P	
Relative Strength, as fabric (compared to Nylon)	1	1	2.2	1	
Relative Cost, weight basis (Compared to Nylon)	1	.97	6.1	.75	
Relative Cost, strength basis (Compared to Nylon)	1	1	2.7	.625	

strength when exposed to water and will be assigned a weighting factor of "1.5" since we feel that it is only half as important as the fabrics resistance to fuel.

4) Resistance to Ultraviolet Radiation

The resistance of a candidate fabric to the affects of ultraviolet radiation exposure will be considered. There have been instances of tank failures due to UV degradation of the fabric. This property will be evaluated by considering the ability of a candidate fabric to resist degradation of its tensile strength when exposed to UV, and will be assigned a weighting factor of "1" because the proper selection of a coating compound will eliminate this problem by screening the fabric from UV,

5) Potential for Adhesion of Coating Compounds

The ability of bonding coating compounds to the candidate fabrics is a major requirement. The 7,000 barrel tank will be fabricated with seams between panels of elastomer coated fabric and all tensile loads in the fabric have to be transferred across the seams through shear forces in the adhesion interface between the coating compound and fabric. The potential for obtaining adhesion between coating compounds and candidate fabrics will be evaluated qualitatively based upon our experience in this product area. This property will be assigned a weighting factor of "3" because it is a critical area in the design of the tank.

6) Puncture and Tear Resistance

The fabric selected for the 7,000 barrel tank must offer protection against tearing after accidental puncture. Puncture and tear resistance will be judged qualitatively and this property will be assigned a weighting factor of "1" because we feel it is only one-third as important as tensile strength and potential for coating adhesion.

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GOODYEAR AEROSPACE CORP AKRON OH ENGINEERED FABRICS DIV F/6 13/4
DEVELOPMENT OF A 5,000 BBL, RUBBERIZED FABRIC FUEL STORAGE TANK—ETC(U)
APR 81 R L SOSNOWSKI DAAK70-79-C-0212
GAC-19-1502 NL

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7) Relative Cost

The cost of the fabric is also a consideration in selection of materials for the tank. However, cost is secondary to proper performance of the fabric and will therefore be assigned a weighting factor of "1".

c Ranking Factors for Candidate Fabrics

1) Tensile Strength

Nylon is considered to be state-of-the-art and is assigned a ranking factor of "1". All other fabrics considered are ranked relative to nylon on a strength per pound of material basis using the data in Table 19. Polyester and fiberglass are also ranked "1", and aramid is ranked "2.2".

2) Fuel Resistance

All fabrics have equal resistance to fuel and are assigned ranking factors of "1".

3) Water Resistance

Nylon is considered to be state-of-the-art and is assigned a ranking factor factor of "1". Aramid is equivalent to nylon and is also ranked "1". Polyester is more susceptible to degradation and is assigned a factor of "0.8". Fiberglass is unaffected by water and is assigned a ranking factor of "1.5".

4) Resistance to Ultraviolet Radiation

Nylon is considered state-of-the-art and is assigned a ranking factor of "1". Polyester is slightly less prone to UV attack and assigned a factor of "1.1". Aramid is slightly more prone to UV attack and is ranked at ".8". Fiberglass is unaffected by UV and is assigned a factor of "1.5".

5) Potential for Adhesion of Coating Compounds

Nylons considered state-of-the-art and is assigned a ranking factor of "1". The potential for obtaining lasting

adhesion to polyester fabrics is considered to be half of that expected for nylon. Obtaining coating adhesion to aramid and fiberglass fabrics, particularly with fuel and/or moisture exposure, is judged to be difficult and these two factors are assigned ranking factors of ".2".

6) Puncture and Tear Resistance

Nylon is considered to be state-of-the-art and is assigned a ranking factor of "1". Tear and puncture resistance is a function of the elongation and modulus of the fabric, on an equal strength basis, a fabric with lower modulus and high elongation will exhibit higher tear and puncture values. Therefore, we have assigned a ranking factor of "1" to polyester, ".8" to aramid and ".7" fiberglass relative to nylon.

7) Relative Cost

Nylon is considered state-of-the-art and is assigned a ranking factor of "1". Cost of fabrics is considered per unit of strength rather than per unit of weight since the critical required property is tensile strength. Ranking factors for the other candidate fabrics are assigned relative to nylon and are based on current prices for commercial lots of fabric. Smaller ranking factors were assigned as costs increased in order to show that higher costs are less desirable. Polyester has approximately the same cost per pound of strength as nylon and is assigned a ranking factor of "1". Aramid cost approximately 2.7 times more than nylon and was assigned a ranking factor of "0.4". Fiberglass was assigned a ranking factor of "1.6".

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d. Consideration of Denier and Weave

The denier of the yarns and the configuration in which they are woven can affect the physical properties of the fabrics selected. The properties affected are fabric porosity, tear strength and puncture resistance. Tensile strength is only indirectly affected, since tensile strength is achieved by designing the fabric with enough yarns to obtain the required strength objective.

Basket weave fabrics are called out in current collapsible fuel tank specifications. There are other weaves available which offer improved puncture and tear resistance, but little work has been done in developing them for collapsible tank constructions. Basket weave fabrics are therefore the only ones which are considered state-of-the-art.

e. Selection of Fabrics

An examination of the cumulative numerical ratings in Table 20 shows that nylon and aramid fabrics have the greatest potential for producing a successful 7,000 barrel collapsible tank. Aramid had a slightly higher numerical rating primarily due to its very large strength to weight ratio, with nylon fabrics being a close second. The potential risks involved with obtaining coating adhesion to polyester and fiberglass fabrics shows that they are not within the state-of-the-art.

TABLE 20 - Fabric Cloths - State Of Art

<u>Fabric Type</u>	<u>Weighting Factor, W</u>	<u>Ranking Factor, (R)</u>	Relative Strength						Resistance To						Tear Potential for Weighted Sum of			
			<u>Cost</u>	<u>UV</u>	<u>Fuel</u>	<u>Water</u>	<u>Puncture</u>	<u>Coating</u>	<u>Adh</u>	<u>Ranking Factor</u>	<u>R</u>	<u>RW</u>	<u>R</u>	<u>RW</u>	<u>R</u>	<u>RW</u>	<u>R</u>	<u>RW</u>
Nylon	(1)	3	(1)	1	(1)	(1)	(1)	3	(1)	1.5	(1)	1	(1)	1	(1)	3	(1)	13.5
Polyester	(1)	3	(1)	1	(1)	1.1	(1)	3	(.8)	1.2	(1)	1	(.5)	1	(.5)	1.5	11.8	
Aramid	(2.2)	6.6	(.4)	.4	(.8)	.8	(1)	3	(1)	1.5	(.8)	.8	(.2)	.8	(.2)	.6	13.7	
Fiberglass	(1)	3	(1.6)	1.6	(1.5)	1.5	(1)	3	(1.5)	2.25	(.7)	.7	(.2)	.6	(.2)	12.65		

5. Selection Of Coated Fabric

a. General

Based on the state-of-the-art analysis of coating compounds and fabrics, the only materials which will be considered in the state-of-the-art analysis of coated fabrics are nylon and aramid fabrics coated with either nitrile rubber or sprayed urethane. The fabrics which will be considered will be evaluated on an equal tensile strength basis using basket weaves. The data to be compared is that shown in the historical coated fabric data shown in Table 4. (Ref 1, 4, and 5).

b. Weighting Factors of Physical Properties To Be Considered

1) Tensile Strength

The tensile strength of the coated fabric is one of the most important physical properties considered and will be assigned a weighting factor of 3 both before and after exposure to weathering. The tensile strength of the coated fabric is strictly a function of the tensile strength of the fabric used in it.

2) Adhesion of Coating

Adhesion of coating compounds to fabrics is another important physical property of the coated fabric because it affects the seam strengths which can be achieved. This physical property will also be assigned a weighting factor of 3 both before and after water and fuel exposure.

3) Diffusion Rate

The rate at which fuel diffuses through the coated fabric is considered to be a less important physical property and it is assigned a weighting factor of 1.

4) Fungus Resistance

The fungus resistance of the coated fabric is judged to be a relatively unimportant physical property in view of the current state-of-the-art and will not be evaluated because all of the materials being considered will meet this requirement as specified in tank purchase descriptions.

5) Puncture and Tear Resistance

The resistance of the candidate coated fabrics to puncture and tear are considered to be minor physical properties and are assigned weighting factors of .5.

6) Blocking

This is judged to be a relatively unimportant physical property. Blocking is a function of the coating compound used and both coating compounds under consideration can be made to meet this requirement.

c. Ranking Factors of Candidate Coated Fabrics

1) Tensile Strength

A ranking factor of 1 is assigned to the original tensile strength of each coated fabric under consideration since they all are being evaluated on an equal strength basis. The ranking factor assigned to tensile strength after weathering is assigned on the basis of the percentage of strength retained by each candidate using current historical data.

2) Adhesion of Coating Compounds

The adhesion of nitrile and urethane coating compounds to nylon fabrics has been well developed over the years and is assigned a ranking factor of 1 as being state-of-the-art.

The adhesion of urethane coating compounds to aramid fabrics is less well developed, and ranking factors are assigned based on

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data available from the experimental aramid tank as ratios to what might be expected from polyurethane on nylon at each exposure condition under consideration.

Data indicates that nitrile elastomers can be adequately bonded to aramid fabrics, but published data is unavailable on the level of adhesion retained after exposure to fuel and water. A short adhesion program was conducted to evaluate coating adhesion to nitrile and polyurethane elastomer coating compounds using twelve experimental adhesive systems and the data appears in Table 24. The data shows that adhesion to aramid is not within the state-of-the-art for fuel storage. The ranking factors assigned for nitrile adhesion to aramid are, therefore, assigned as 0.5 before immersion and 0.2 after immersion.

3) Diffusion Rate

The rate of fuel diffusion through coated fabrics is controlled by the use of barrier films and fabric adhesives. It is difficult to rank the potential of coated fabrics meeting this requirement at this time and all candidate coated fabrics will be assigned a ranking factor of 1.

4) Puncture and Tear Resistance

Ranking factors for puncture and tear resistance are based on a comparison of all candidate coated fabrics to nitrile coated nylon which is assigned a ranking factor of 1 and is considered state-of-the-art.

The tear resistance of urethane coated nylon and aramid fabrics is approximately one-half of that obtained on nitrile coated fabrics. These two materials are, therefore, assigned a ranking factor of 0.5. The tear resistance of nitrile coated aramid is unknown, but should be approximately half of that for nitrile coated nylon based on the tear properties of uncoated aramid. Therefore, a ranking factor of 0.5 is assigned to nitrile coated aramid since physical properties are being evaluated on equal original cloth strength basis.

TABLE 21 -- COATING ADHESION TO ARAMID CLOTH

Adhesive System	Peel Adhesion, Lbs/In					
	M901 Nitrile		80C29 Urethane			
	Original	7 Days 160°F H ₂ O	7 Days 160°F Fuel*	Original	7 Days 160°F H ₂ O	7 Days 160°F Fuel*
D1660F484	31	5	12	30	6	13
D1660F484 + 2412C	52	5	7	36	5	16
P-6965	32	5	2	12	6	7
P-6965 + 2412C	6	3	4	6	3	3
D1660F543	33	6	9	20	14	12
D1660F543 + 2412C	45	9	5	20	6	17
Chemlok 402	37	3	15	16	8	9
Chemlok 402 + 3412C	32	4	2	19	6	6
Chemlok 234B	21	1	6	20	8	6
Chemlok 234B + 2412C	13	3	5	22	3	4
TS-3563-3	37	5	18	24	3	7
TS-3563-3 + 2412C	6	6	32	6	2	3

*ASTM D-471 Reference Fuel D

An examination of historical data shows that the puncture resistance of each of the coated fabrics considered is proportional to the tensile strength of the reinforcing fabric used, and that the ratio is approximately constant. Since all of the fabrics are being evaluated on an equal tensile strength basis, their puncture resistance will also be approximately equal. Therefore, a ranking factor of 1 was assigned for the puncture resistance of all candidate coated fabrics.

d. Selection of Coated Fabric

An examination of the cumulative numerical ratings in Table 21 shows that polyurethane coated nylon is the coated fabric with the best combination of physical properties for the intended service. Nitrile coated nylon fabric has the second highest numerical rating.

6. Analysis of Candidate Coated Fabric Seams

a. General

The seam constructions which will be evaluated will be those fabricated from the four leading candidate coated fabrics selected in the previous section. All candidate seams will be evaluated on the basis that they are prepared from fabrics of equal tensile strength. The data which will be compared is the historical seam data shown in Table 5 (ref. 1, 4, and 5).

b. Weighting Factors of Physical Properties To Be Considered

1) Tensile Strength

The tensile strength of seams is one of the most important physical properties to be considered in designing the proposed tank. The tensile strengths of candidate seams, both before and after exposure to water and fuel, will be assigned weighting factors of 3.

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TABLE 22 -- COATED FABRIC STATE OF ART

Coating/ Cloth	Diffusion Rate	Adhesion of Coating												Summary of Weighted Ranking Factors		
		1	.5	.5	Tear	Puncture	Initial	After Water Immersion	After Fuel Immersion	R	RW	R	RW	R	RW	Σ RW
Weighting Factor, R	R	RW	R	RW	R	RW	R	RW	R	RW	R	RW	R	RW	R	RW
<u>Coated Fabrics</u>																
Nitrile/Nylon	(1)	1	(1)	3	(1)	.5 (1)	.5 (1)	3 (.3)	.9 (.5)	1.5 (.8)	2.4	12.8				
Polyurethane/Nylon	(1)	1	(1)	3	(.5)	.25 (1)	.5 (1)	3 (.6)	1.8 (.6)	1.8 (.9)	2.7	14.05				
Nitrile/Aramid	(1)	1	(1)	3	(.5)	.25 (1)	.5 (.2)	.6 (.2)	.6 (.2)	.6 (.2)	.6	.6	7.15			
Polyurethane/ Aramid	(1)	1	(1)	3	(.5)	.25 (1)	.5 (.5)	1.5 (.5)	1.5 (.4)	1.5 (.1)	3	12.25				

2) Seam Peel Adhesion

The peel strength of the candidate seams is also a major consideration since tensile loads in adjacent fabric patterns must be transferred across the seam. Therefore, the peel strength of seams, both before and after fuel and water soak will be assigned weighting factors of 3.

3) Dead Load Shear Resistance

Seams made from fabrics coated with thermosetting compounds will all pass the 8 hour dead load test called out in the purchase description and, therefore, would all have the same weighted ranking factor. This physical property, therefore, will not be included in the matrix table.

c. Ranking Factors of Candidate Seams

1) Tensile Strength

An examination of historical seam tensile strength data shows that seams made using the sprayed polyurethane process with nylon or aramid fabric and by vulcanizing seams using precured nitrile coated nylon fabric will produce seams which are strong enough to cause failure in the coated fabric rather than in the seam. Unimmersed seam tensile strengths of these materials are, therefore, assigned a ranking factor of 1. There is little data available on the seam strength possible using vulcanized seams in precured nitrile coated aramid, and it is therefore, assigned a ranking factor of .5.

Ranking factors for tensile strengths of seams immersed in water and fuel were assigned as the percentage of tensile strength retentions after 42 days exposure based on historical data available on seams made by each process. No immersion data was available on seams made using nitrile coated aramid and it was assigned a ranking factor of .2.

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2) Seam Peel Adhesion

Examination of historical tank seam peel adhesion data shows that the seams made using the urethane spray process or vulcanization from precured nitrile coated nylon fabric will produce initial seam peel adhesion values which are approximately equal and they are, therefore, assigned a ranking factor of 1. Seam peel strength in urethane spray coated aramid produced a seam peel strength of approximately one-half these values and was, therefore, assigned a ranking factor of .5. There is little data available on nitrile coated aramid, but we assume that peel adhesion equivalent to urethane coated aramid can be obtained and it is assigned a ranking factor of .5.

Ranking factors for peel adhesion of seams immersed in water and fuel were assigned as the percentage of peel adhesion retained after 42 days immersion from historical data on seams made by each process. There is no data available on the peel strength of seams made from nitrile coated aramid and it is, therefore, assigned a ranking factor of .2.

d. Summary

An analysis of the data in Table 22 shows that seams made by the polyurethane spray process using nylon fabric have the greatest potential for producing a large capacity tank with the required physical properties. Seams made by vulcanized precured nitrile coated nylon showed the second greatest potential. Seams in rubber coated aramid fabrics had the poorest overall properties of the group.

7. Analysis of Fitting Adhesion

a. General

The materials which will be evaluated in this study will be the same coated fabrics examined in the preceding seam study. Fitting adhesion will be based on all coated fabrics having the same original tensile strength.

TABLE 23 -- CHARACTERISTICS OF SEAMS, STATE OF ART

<u>Seam Type</u>	<u>Weighing Factor, W</u>	<u>Tensile, Pounds Per Inch</u>			<u>Peel Adhesion</u>			<u>Summary Of Weighted Ranking Factors</u>		
		<u>Initial</u>	<u>After Water Immersion</u>	<u>After Fuel Immersion</u>	<u>After Water Immersion</u>	<u>After Fuel Immersion</u>	<u>After Fuel Immersion</u>	<u>Initial</u>	<u>Water Immersion</u>	<u>Fuel Immersion</u>
		<u>Ranking Factor, R</u>	<u>R</u>	<u>RW</u>	<u>R</u>	<u>RW</u>	<u>R</u>	<u>RW</u>	<u>R</u>	<u>RW</u>
Nitrile/ Nylon	(1)	3	(.7)	2.1	(.8)	2.4	(1)	3	(.9)	2.7
Urethane/ Nylon	(1)	3	(1.2)	3.6	(1.3)	3.9	(1)	3	(.9)	2.7
Nitrile/ Aramid	(.5)	1.5	(.2)	.6	(.2)	.6	(.5)	1.5	(.2)	.6
Urethane/ Aramid	(1)	3	(.9)	2.7	(.9)	2.7	(.5)	1.5	(.7)	2.1
										14.7
										18.3
										5.4
										11.7

b. Weighting Factors of Physical Properties To Be Considered

1) Bond Strength

The bond strength of candidate coated fabrics to aluminum fittings, both before and after immersion in fuel and water, will be assigned a weighting factor of 3.

2) Peel Adhesion To Metal

The peel adhesion between each candidate coated fabric and aluminum, both before and after immersion in fuel and water will be assigned a weighting factor of 3.

3) Dead Load Shear Resistance

This is a relatively unimportant physical property since historical data shows that if coated fabric is properly bonded to fittings, as evidenced by bond and peel strength, they will not slip. Therefore, this physical property will not be ranked in the fitting analysis.

c. Ranking Factors of Candidate Coated Fabrics

1) Bond Strength

Examination of historical fitting bond strength data shows that the adhesion between fittings and both urethane and nitrile coated nylon fabric and urethane coated aramid fabric are sufficient to break the fabric outside the bond area. These materials are, therefore, assigned a ranking factor of 1. There is little data on the adhesion of nitrile coated aramid fabric to aluminum fittings and it is, therefore, assigned a ranking factor of .5.

Ranking factors for coated fabric to fitting bond strengths after 42 days immersion in water and fuel were assigned as the percentage of strength retained after 42 days exposure based on historical data. No immersion data was available on nitrile coated aramid to aluminum and it was assigned a ranking factor of .2.

2) Peel Adhesion to Metal

Examination of fitting peel adhesion data for the candidate coated fabrics shows that urethane and nitrile coated nylon have peel values approximately equal, with urethane coated aramid exhibiting about half this value. The nylon coated fabrics are, therefore, assigned ranking factors of 1 and the urethane coated aramid .5. There is little data available on nitrile coated aramid, but we assume peel strength at least equal to that obtained with urethane coated aramid can be obtained and it is also assigned a ranking factor of .5.

Ranking factors for peel adhesion after water and fuel immersion are based on the percentage of peel strength retained after 42 days exposure based on historical data for each candidate material. There is no fitting peel strength data available on nitrile coated aramid after fuel and water immersion and it is, therefore, assigned a ranking factor of .2.

d. Summary Fitting Adhesion Results

An analysis of the data in Table 23 shows that the potential for developing adhesion to anodized aluminum fittings is best for nitrile coated nylon fabrics, with urethane coated nylon being second best.

REF ID: A01380

TABLE 24 -- CHARACTERISTICS OF BONDS TO FITTINGS, STATE OF ART

Weighting Factor, W	Initial	Bond Strength				Peel Adhesion				Summary Of Weighted Ranking Factors		
		After Water Immersion	After Fuel Immersion	Initial	After Water Immersion	After Fuel Immersion	Initial	After Water Immersion	After Fuel Immersion	Initial	After Water Immersion	Initial
Weighting Factor, R	R	RW	R	RW	R	RW	R	RW	R	RW	R	RW
Ranking Factor, R	R	RW	R	RW	R	RW	R	RW	R	RW	R	RW
Adherance												
Nitrile/ Nylon	(1)	3	(.8)	2.4	(.5)	1.5	(1)	3	(1)	3	(.5)	1.5
Urethane/ Nylon	(1)	3	(.5)	1.5	(.5)	1.5	(1)	3	(.7)	2.1	(.5)	1.5
Nitrile/ Aramid	(.5)	1.5	(.2)	.6	(.2)	.6	(.5)	1.5	(.2)	.6	(.2)	.6
Urethane/ Aramid	(1)	3	(.8)	2.4	(.7)	2.1	(.5)	1.5	(.2)	.6	(.1)	.3

F. Summary of State-Of-The-Art Studies**1. Preliminary Design Analysis**

The analysis of fabric stresses and tank weights shows that collapsible fuel storage tanks of 5000, 7000 and 10,000 barrel capacity are within the state-of-the-art depending on the design factor selected. This analysis also demonstrated that for a given design factor the goals of simultaneously minimizing tank weight and ground area are mutually incompatible. As the flat dimensions of the tank are reduced, the fill height must go up in order to achieve the same volume, and the additional fabric weight required at this higher stress level increases the weight of the container even though the surface area of the tank has been reduced.

2. State-Of-The-Art of Fabrication Techniques

Our analysis showed that fabrication of a 7000 barrel collapsible petroleum storage container is within the state-of-the-art of current manufacturing and fabrication techniques and that any potential material handling problems which might arise due to the weight and bulk of material involved can be eliminated by sectionalizing the construction and by establishing a proper sequence of fabrication operations. The techniques suitable for manufacture of this container are (1) fabrication using a seam press and pre-cured coated fabrics, and (2) fabrication using the sprayed urethane process.

3. State-Of-The-Art of Materials**a. Coating Compound**

Of the coating compounds considered, nitrile and polyurethane elastomers are considered to be within the state-of-the-art. Thermosetting elastomers are preferred because they do not exhibit as much cold flow as thermoplastic coating compounds. Cold flow could cause seam slippage in tanks designed with high fabric tensions.

REF ID: A01380

Thermosetting nitrile and polyurethane compounds will both produce acceptable tanks. However, our state-of-the-art coating compound analysis in Task 3 showed that nitrile compounds have somewhat better overall physical properties (Table 14). It should also be noted that nitrile compounds are significantly less expensive than polyurethane.

b. Fabric

Nylon fabric is currently used as the reinforcing material in collapsible petroleum storage tanks. It was found to be the most cost effective material studied and adhesive systems for obtaining coating adhesion are well developed. Its principal shortcoming is degradation when exposed to ultraviolet light. This potential problem can be virtually eliminated by selecting a coating compound which screens the nylon from ultraviolet radiation.

Aramid fabrics are strong, light and resistant to high temperatures and chemical attack. They are, however, susceptible to ultraviolet degradation like nylon. The properties that make them resistant to chemical attack also make it difficult to bond coating compounds to them, particularly when these bonds must also resist attack by hydrocarbon fluids and moisture. Since the mechanical performance of collapsible tanks depends on the strength of the seams used in their construction, adhesion of the coating compound during fuel exposure becomes extremely important. Fabric stresses in the tank envelope must be transferred across the adhesion interfaces between fabric and coating compound in seams between panels of coated fabric used in manufacturing large tanks. Aramid fabrics are also known to have poor physical properties in compression, which causes them to degrade during cyclic loading. The 7000 barrel container is not expected to see rapid cyclic loading, but we are unsure of the affects of long term storage and subsequent shipment of aramid reinforced tanks which are folded and rolled into packaged units. These folds could potentially see compressive forces. Aramid fabrics, therefore, are not recommended for use in the 7000 barrel container.

Our study showed that the basket weave fabrics currently used in collapsible tank designs have sufficient tear strength to meet current need. There are other weaves available which offer improved tear strength. This would be a desirable feature if there were a history of tanks tearing open after small arms fire or accidental puncture, but we have been unable to substantiate that this is a severe problem. There is also a lack of data on the seam strength of coated fabrics made using high tear fabrics other than basket weaves, and we are uncertain of their fuel diffusion properties if barrier coatings are not used. We, therefore, feel that basket weave fabrics are state-of-the-art and are the leading candidate weaves for the 7000 barrel tank.

c. Selection of Coated Fabric

The leading candidate coated fabrics are thermosetting nitrile and polyurethane compounds coated on nylon basket weave fabrics. Both have roughly equivalent seam adhesion and tensile strength originally and after fuel soak (Tables 4 and 5). The seam strength and coating adhesion after water soak is better on seams made with Goodyear's new hydrolysis resistant polyurethane which caused the numerical ratings for seams and coated fabric made from this material to be larger than those for the nitrile coated fabric (Tables 21 and 22). However, nitrile fabrics have a history of producing reliable tanks that will meet or exceed military specification requirements for collapsible fuel storage tanks (ref 1, 2, and 3). It has been Goodyear's experience that tanks can be produced cost effectively using nitrile coated fabrics seamed together in a seam press.

d. Selection of Candidate Coated Fabrics

This state-of-the-art analysis has shown that basket weave nylon cloths coated with nitrile or sprayed polyurethane elastomers are the best candidate coated fabrics for the prototype 7000 barrel tank. Collapsible tanks have been manufactured in production quantities using cloth weights up to 12 oz/sq yd. However, one of the objectives of this project is to reduce the ground area of the tank which means that tanks will have to be operated at higher fill ratios which results in higher envelope stress levels.

10-1517 711
REF: EO1 360

Stronger fabrics may be required for tanks operating at higher stress levels and, therefore the physical characteristics of 18 and 24 oz/sq yd basket weave nylon coated fabrics will be evaluated in addition to 12 oz/sq yd fabric.

G. Analyze Properties of Leading Candidate Materials - Task 4

1. Introduction

Several basket weave nylon cloths were selected for evaluation in this phase of the project. These cloths were coated with elastomer and their physical properties determined. Data was obtained on bare cloth, coated fabrics, and seams made from each of the coated fabrics selected. All testing was performed in accordance with the requirements of the experimental purchase description of the 7000 barrel tank. The test methods used are also referenced in the data tables presented in the discussions which follow.

The requirements specified in the purchase description were approached as being goals rather than firm requirements especially with respect to reinforcing fabrics. Acceptable tanks can be manufactured using fabrics lighter than the 18-20 oz/sq yd fabric required to produce a 1000 lb/in breaking strength. The final fabric weight recommended for the prototype will be selected on the basis of the trade-off study in paragraph F., which, because of the goals of obtaining minimum weight and ground area, and acceptable operational characteristics, may require that a fabric lighter than 18 oz/sq yd be selected.

2. Physical Properties of Cloth

Five basket weave nylon cloths were selected for study. All but one of the cloths selected are currently being used in the manufacture of other products produced by Goodyear. The fifth cloth selected (Code RF 427) is currently being evaluated by Goodyear for another product which offers improved tear strength. This cloth may be of benefit in the 7000 barrel tank because its high tear strength would improve the tank's resistance to propagation of a tear in the event of a cut or puncture.

The data obtained on these cloths is shown in Table 25. All of the cloths selected are suitable for use in the 7000 barrel tank depending on the operating stress level selected for the final tank configuration.

3. Physical Properties of Coating Compounds

The leading coating compounds are nitrile and polyurethane. The physical properties of Goodyear's nitrile and urethane compounds appear in Table 26. This data was taken from References 1 and 5. This data shows that both coatings have satisfactory physical properties.

4. Physical Properties of Coated Fabrics

Each of the five cloths identified in paragraph G.2. were coated with nitrile elastomer using factory processing equipment and procedures. The physical properties of each of the resultant coated fabrics were determined and the data appears in Table 27. Fabrics were not coated with Goodyear's polyurethane because of economic considerations (see paragraph H.2.c.).

The data shows that the nitrile coated fabrics tested have the necessary tensile properties and resistance to fuel and water. However, the fabrics made with 18 and 24 oz/sq yd nylon will not meet the cold flex requirement. Also the XA22A566 (18 oz nylon) does not meet the initial diffusion requirement. None of the fabrics made with 18 or 24 oz/sq yd nylon meet the diffusion requirement after cold flex test which was probably due to the coating compound being cracked in each sample.

The ability of XA22A565 and XA22A566 to resist tear propagation was also determined using a cylinder burst test. Five cylinders were prepared using each material with various slit lengths. A photograph of the test apparatus is shown in Figure 8 and diagrammatically in Figure 9. The cylinders were mounted in the apparatus and a large volume of high pressure air was introduced instantaneously. Pressure and circumference were measured during inflation and hoop stress at rupture calculated. The data resulting from this testing is shown in Figure 10 which shows the hoop stress required to cause tear propagation in the two fabrics studies as a function of the length of a cut or puncture.

TABLE 25 -- PHYSICAL PROPERTIES OF CANDIDATE CLOTHS

Property	Requirements	Test Method	Actual Data For Fabric Codes					
			Fed No.	Std 191	3640N	290N	RF429	3629N
Thread count, warp and fill Weave	Record Record	5050 Visual	42x42 2x2		39x40 2x2	25.26 18.18	33x34 24.82	40x30 17.59
Weight, oz/sq yd	Record	5041	9.66		11.6 .020	.051	.061	.037
Thickness, Inches	Record	5030.2	1/		.020			
Tearing strength warp and fill, lbs	Record	5134	162x146		149x156	867x595	912x1158	252x276
Breaking Strength warp and fill, lbs/inch	Record	5104	2/	725x702	720x718	1110x990	1258x1340	1087x1067
Weathering resistance (after 100 hrs exposure at 5% elongation), %	50% Retention of Orig.	5804	2/					
	Break Strength, min.			93x92	104x95	91x102	100x93	97x99

FOOTNOTES:

- 1/ The edges of the tear-test specimen were coated by dipping with an adhesive that precluded yarn slipping while under test.
- 2/ Alternate corex D filters were removed. Specimens were raveled for Method 5104 after accelerated weathering.
- 3/ End of specimens for breaking strength test were coated by dipping into an adhesive that precluded yarn slipping under test. Only those parts that were held in the clamps during test were treated.

TABLE 26 -- PHYSICAL PROPERTIES OF CANDIDATE COATING COMPOUNDS

Property	Requirement		Test Paragraph or Test		Nitrile		Polyurethane		Actual Data	
	Interior & Top Exterior	Bottom Exterior	Method of Fed. Test Method Std. 601	Method Std. 601	M908 14 Day	70 Day	80C29 14 Day	70 Day	14 Day	70 Day
Initial Tensile Strength, psi Stress at 200% Elongation psi	Record	Record	4111	4127	5250	4259	4935	4935		
Ultimate Elongation, %	Record	Record	4131	-	2429	1875	2013			
After Immersion in Distilled Water, (pH of 7.0 +0.2) at 160°F +2°F for 14 Days (2)	Record	Record	4121	545	310	370	360			
Volume Change, %	Record	Record	6211	-	-	1.9	2.3	1.1	1.3	1.9
Initial Tensile Strength Retained (1)										4.6
a. Interior compounds & barrier (3), % (min)	60	40	6111 (para 4.8.1 of Method 6111 applies)	95.2	106.4 (42 Day)	72	-	-	-	-
b. Exterior top compounds, (4) % (min)	60	40	-	-	-	-	65	-	-	-
c. Exterior bottom compounds, (4) % (min)	50	25	-	-	-	-	-	-	60	30
After immersion in ASTM D-471, Reference Fuel D. (6)	14 Days (2)	70 Days								(Note 7a)
Volume Change	Record	Record	6211							
Initial tensile strength retained (1)			6111 (para 4.8.1 of Method 6111 applies)							
a. Interior Compounds & barrier, (3), % (min)	40	30	74.6	74.6	63	53	-	-	-	-
b. Exterior top compounds, (4) % (min)	40	30	-	(42 Day)	-	-	43	36	-	-
c. Exterior bottom compounds (4) % (min)	35	25	-	-	-	-	-	-	44	41
After accelerated weathering for 500 hrs (exterior compounds only) (6)(5)										
Initial tensile strength retained (1) %			92.0	92	93	93	88			
Fuel Contamination (interior compounds only)			4.4.1							
Unwashed existent gum, mg/100 ml (max) 20			4.4.1	12.6	7.0	-	-			
Heptane washed existent gum, mg/100 ml (max) 5			4.4.1	0.1	2.1	-	-			

TABLE 26 -- FOOTNOTES

- (1) The percentage tensile strength retained is:

Tensile Strength Retained After Immersion or Weathering x 100
Initial Tensile Strength Value Actually Obtained (Average of 3 or More Samples)

- (2) Tolerance for immersion periods: +2 hours

- (3) Interior compounds: All compounds between the fabric and the inside of the tank.

- (4) Exterior compounds: All compounds between the fabric and the outside of the tank.

- (5) Exposed at 10% elongation with alternate Corex D filters in place.

- (6) 60% iso-octane and 40% toluene.

- (7) Actual Test Fluid:

a. FED-STD-601 Method 6001 - 60% No. 4, 25% No. 8, 15% No. 9 - (40% Aromatic)

b. TT-S-735 Type II (40% Aromatic)

TABLE 27 -- PHYSICAL PROPERTIES OF CANDIDATE CURED COATED FABRICS 1/

Property	Goal	Test Paragraph Or Test Method of Fed. Std. No. 191	Actual Coated Fabric Data, XA22AXXX (Cloth Code)		
			564 (3640N)	565 (290N)	566 (RF-427) (3629N)
Thickness, inches			.065	.072	.092
Weight, oz./sq yd	Record	5030-1	.065	.092	.109
Diffusion Rate F1 Oz/Sq Ft/Day	Record	5041	.064	.185	.35
	.10 fl oz/sq ft per 24 hrs (max)	4.4.2	.056	.056	.084
Tearing Strength, warp and fill, lbs/inch	50 pounds (min)	5134	73x58	62x52	76.58
Breaking Strength, Warp and Fill lbs/inch	1000 pounds/inch (min)	5102 2/	811x606	751x615	.072
Weathering resistance after 500 hrs exposure at 100 pounds/in (initial tension), warp and fill, %	80% retention of initial breaking strength (min)	5804/5102-3/	--	--	--
Puncture Resistance, lbs	200 lbs (min)	4.4.3/5120	201	204	226
Low Temperature Crease Resistance:					
a. Appearance after Unfolding	No cracking, peeling or delamination	4.4.4	OK	OK	OK
b. Diffusion rate after low temperature crease resistance test	.10 fl oz/sq ft per 24 hrs (max)	4.4.2	.062	.066	.129
Fungus Resistance	No cracking, blistering, or delamination of coating. Retention of breaking strength 50% (min)	5762 5/	OK	OK	OK
Blocking	Specimens to separate within 5 seconds	621x637 (76x72)	706x629 (94x70)	1023x689 (93x81)	823x1107 (95x136)
Coating Adhesion (initial) 1bs/in	20 pounds/inch (min)	4.4.6	7/	92	70
Coating adhesion after immersion in distilled water at 160°F +2°F for the following durations:					
14 Days, 1bs/in, (Z)	10 lbs/in or 30% of initial (min) 4/	4.4.6	--	72(78.8)	32(66.9)
42 Days, 1bs/in, (Z)	5 lbs/in or 20% of initial (min) 4/	4.4.6	--	71(77.2)	14(20.3) 7/
Coating adhesion after fuel immersion in reference fuel D at 6/ 160°F +2°F for the following durations:					
14 Days, 1bs/in, (Z)	10 lbs/in or 40% of initial (min) 4/	4.4.6	--	46 (49.9)	48 (70)
42 Days, 1bs/in, (Z)	10 lbs/in or 30% of initial (min) 4/	4.4.6	--	47 (51.0)	40 (58.0)

TABLE 27 -- FOOTNOTES

- 1/ Properties after cure.
- 2/ Specimens were 1.0 inch wide. Care was taken to cut specimens parallel to and following the curvature of the threads of the fabric.
- 3/ Specimens were exposed to accelerated weathering before stripping or cutting to 1.0-inch width. (Note 1.) Specimens were tensioned in the direction of the 6-inch length, under a stress of 100 lb/in \pm 5 lb/in for 60 seconds. While still under stress the specimen was clamped to maintain the initial (one minute) elongation without slippage. While still so elongated, specimens were exposed by Method 5804 of FED. Test Method Std. 191. Alternate Corex D filters were removed during test.
- 4/ Whichever is the greater requirement.
- 5/ Method 5762 except that the specimens were prepared by Note 1/ after soil burial and the number of specimens was reduced from 40 to 12. Leaching of the specimens is unnecessary.
- 6/ Reference fuel D is ASTM D471, 60% iso-octane and 40% toluene.
- 7/ Fabric adhesive porous.

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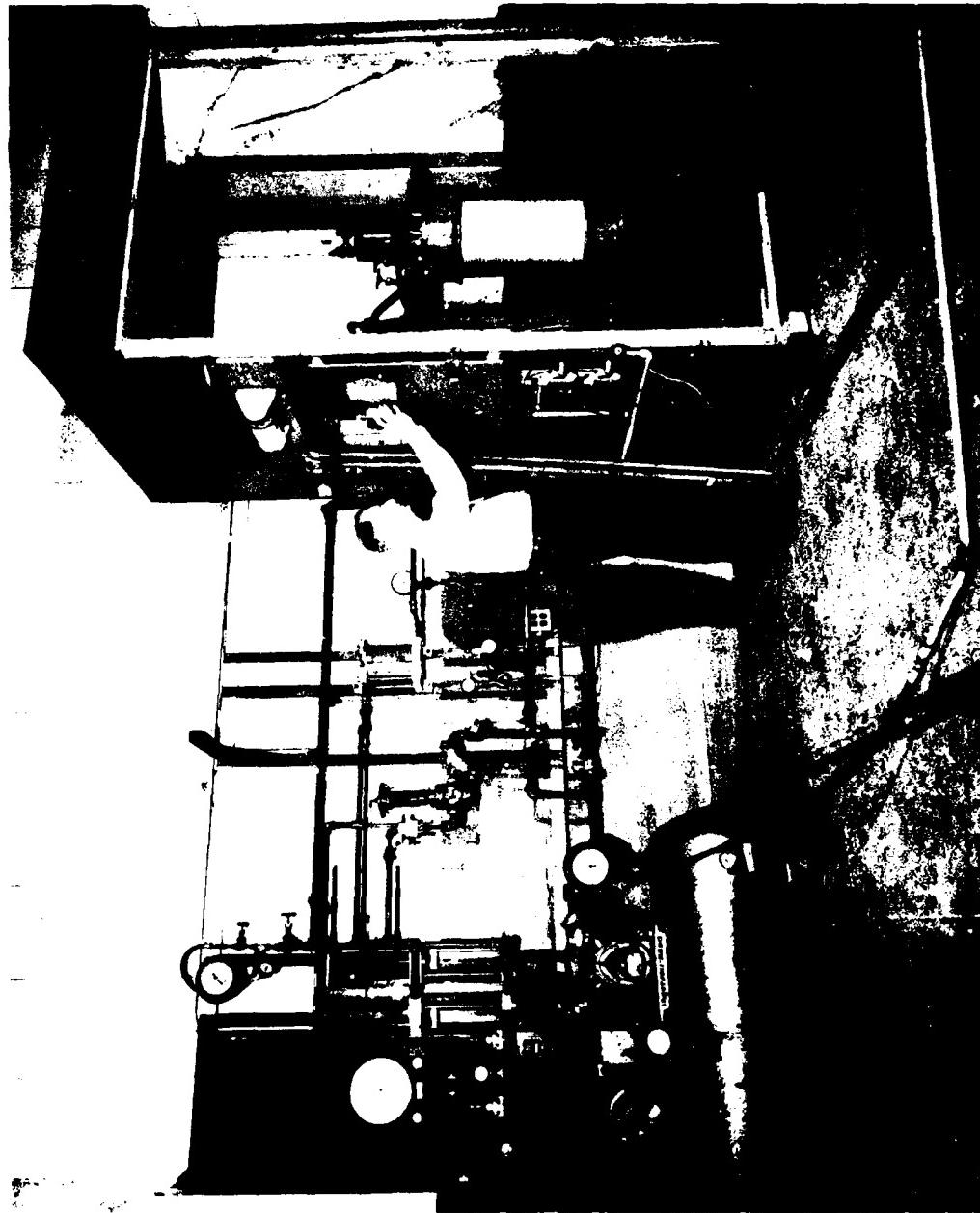


FIGURE 8 -- CYLINDER BURST TEST APPARATUS

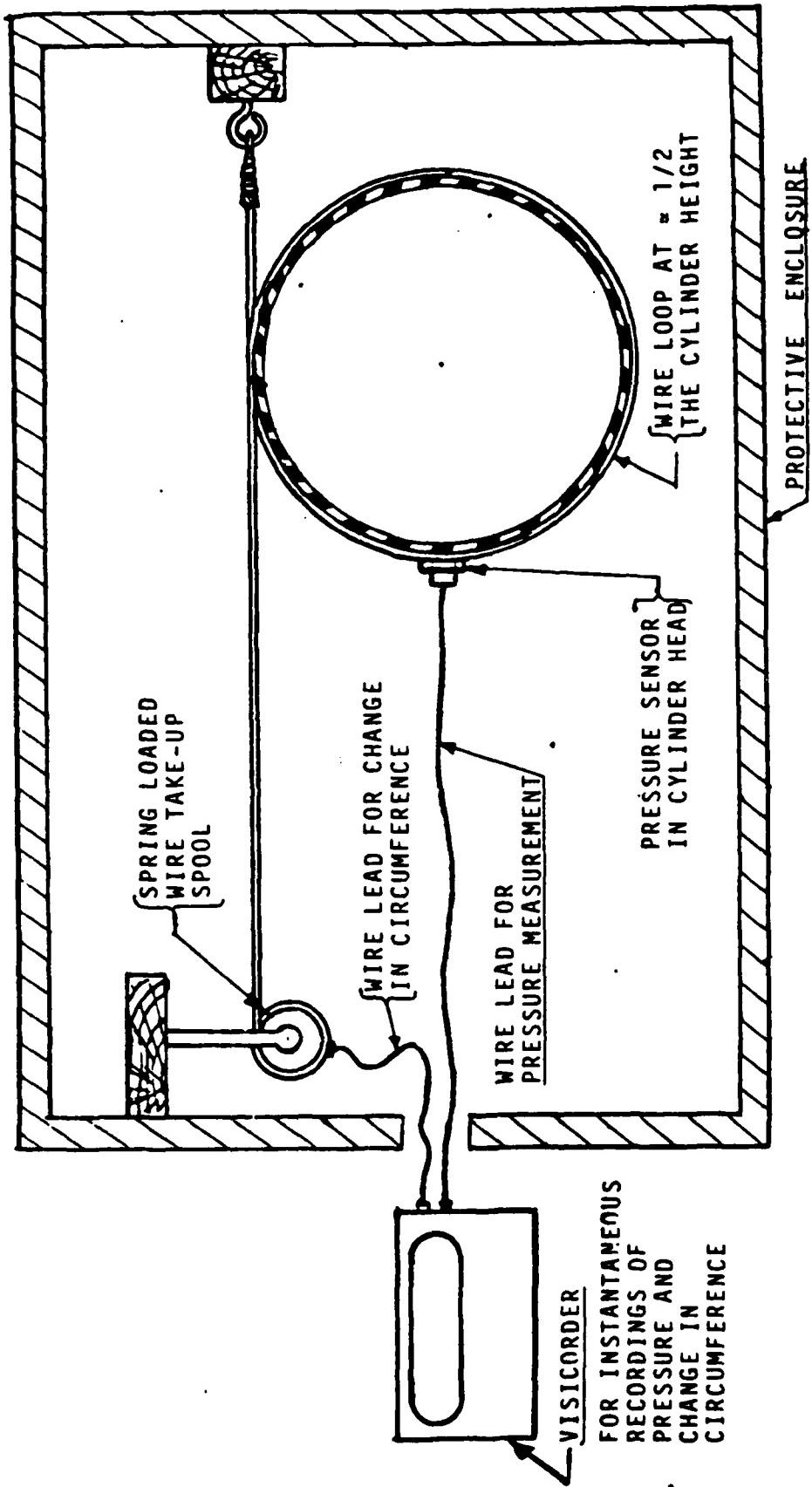
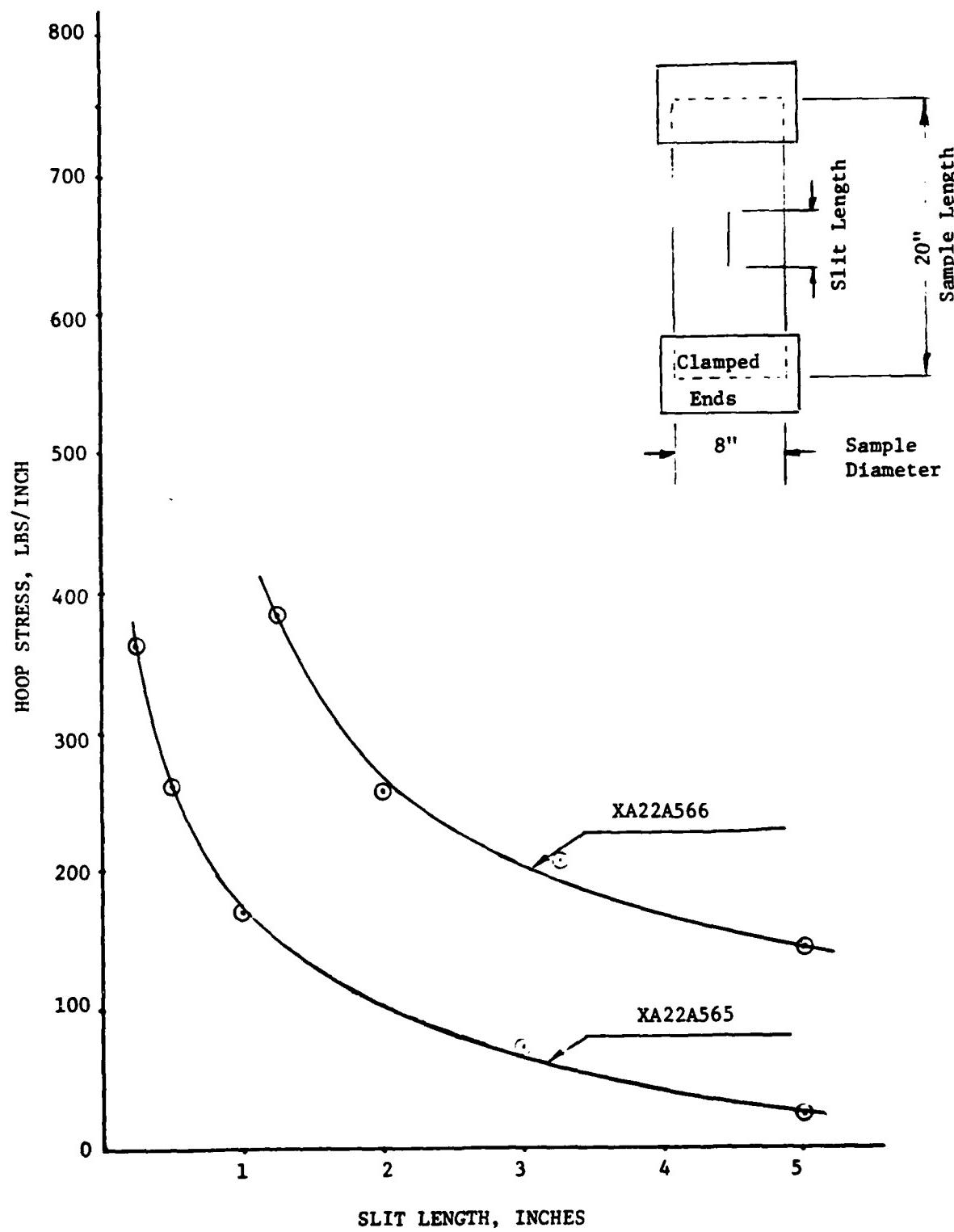


FIGURE 9

CYLINDER BURST TESTS - DATA RECORDING SET-UP

FIGURE 10 -- FABRIC STRESS AT WHICH TEARS PROPAGATE VERSUS SLIT LENGTH



5. Physical Properties of Coated Fabric Seams

Seams were made from the two leading candidate coated fabrics using a seam press. The seams were made using HC-283 seam adhesive and were unsewn. Two-inch overlaps were used in samples made from XA22A565, and 3" overlaps were used for XA22A566. The data on the seam tests appear in Table 28.

Seam samples of XA22A565 and XA22A566 prepared as described in the preceding paragraph were also subjected to dead load tests at various stress levels. Tests were run with the samples dry and also while immersed in JP-4 fuel and in water. All testing was performed at ambient temperature. The resulting data appears in Figures 11 and 12.

The dead load data was somewhat inconclusive. Data obtained on XA22A566 developed approximately straight line semi-logarithmic plots, while the data generated for XA22A565 showed a great deal of scatter. Several samples of XA22A565 were tested in an attempt to generate more uniform results, but it became obvious that there were problems in the testing which could not be resolved in the scope of the present contract. It was observed that samples were loading unequally across the width of the seam, which caused premature sample failure starting at one edge. This may have been caused by several factors. Samples were observed to slip at the edges of test jaws even though C-clamps were used to try to stop it. Also, panographing of cords was observed across the seam which caused them to move off the center of loading. Actual tanks would not be subject to these phenomenon because seams run continuously between the edges of the tank.

It should also be noted that the tests conducted in fuel and water were probably more severe than actual tanks would see because samples were totally immersed in the test fluid and cut fabric edges allowed fuel to wick along cloth yarns to totally saturate the seams. Actual tanks have fuel on only one side of the fabric and all cut edges are covered by rubber coating.

TABLE 2A - PHYSICAL PROPERTIES OF CURED SEAMS

<u>Property</u>	<u>Coal</u>	Test Paragraph or Test Method		Actual Data, XA22A55		<u>568</u>
		No. 401	8311/4.4.7	566	567	
Breaking Strength (Initial)	1000 lbs/in (min) ^{2/}	---	---	698	1160	1335
Breaking Strength after Immersion in Distilled Water at 160°F +2°F for the following durations:						
16 Days	800 lbs/in (min)	8311/6001/4.4.7	---	556(80)	1032(89)5/	790(82)5/
42 Days	400 lbs/in (min)	8311/6001/4.4.7	---	523(75)	---	---
Breaking Strength after Immersion in Ref. Fuel D 4/ at 160°F +2°F for the following durations:						
16 Days	800 lbs/in (min)	8311/6001/4.4.7	---	593(85)	945(81)5/	585(61)5/
42 Days	400 lbs/in (min)	8311/6001/4.4.7	---	741(106)	---	---
Dead Load Shear Resistance Under 100 lbs/in Stress at 200°F for 8 hours	.125 in slipage (max)	4.4.8	passed	6/	6/	6/
Peel Adhesion (Initial)	20 lbs/in (min)	8011	6/	79	6/	6/
Peel Adhesion after Immersion in Distilled Water at 160°F +2°F for the following Durations:						
16 Days	10 lbs/in or 30% of Initial (min) ^{3/}	8011/6001/4.4.7	6/	79(100)	6/	6/
42 Days	5 lbs/in or 20% of Initial (min) ^{3/}	8011/6001/4.4.7	6/	66(84)	6/	6/
Peel Adhesion after Immersion in Ref. Fuel D 4/ at 160°F +2° for the following Durations:						
16 Days	10 lbs/in or 40% of Initial (min) ^{3/}	8011/6001/4.4.7	6/	43(54)	6/	6/
42 Days	10 lbs/in or 30% of Initial (min) ^{3/}	8011/6001/4.4.7	6/	42(53)	6/	6/

FOOTNOTES:

1/ Properties after cure.

2/ All specimens broke in the coated fabric. Failure of any specimen in a seam area at any value shall constitute failure of this test.

3/ Whichever is the greater requirement.

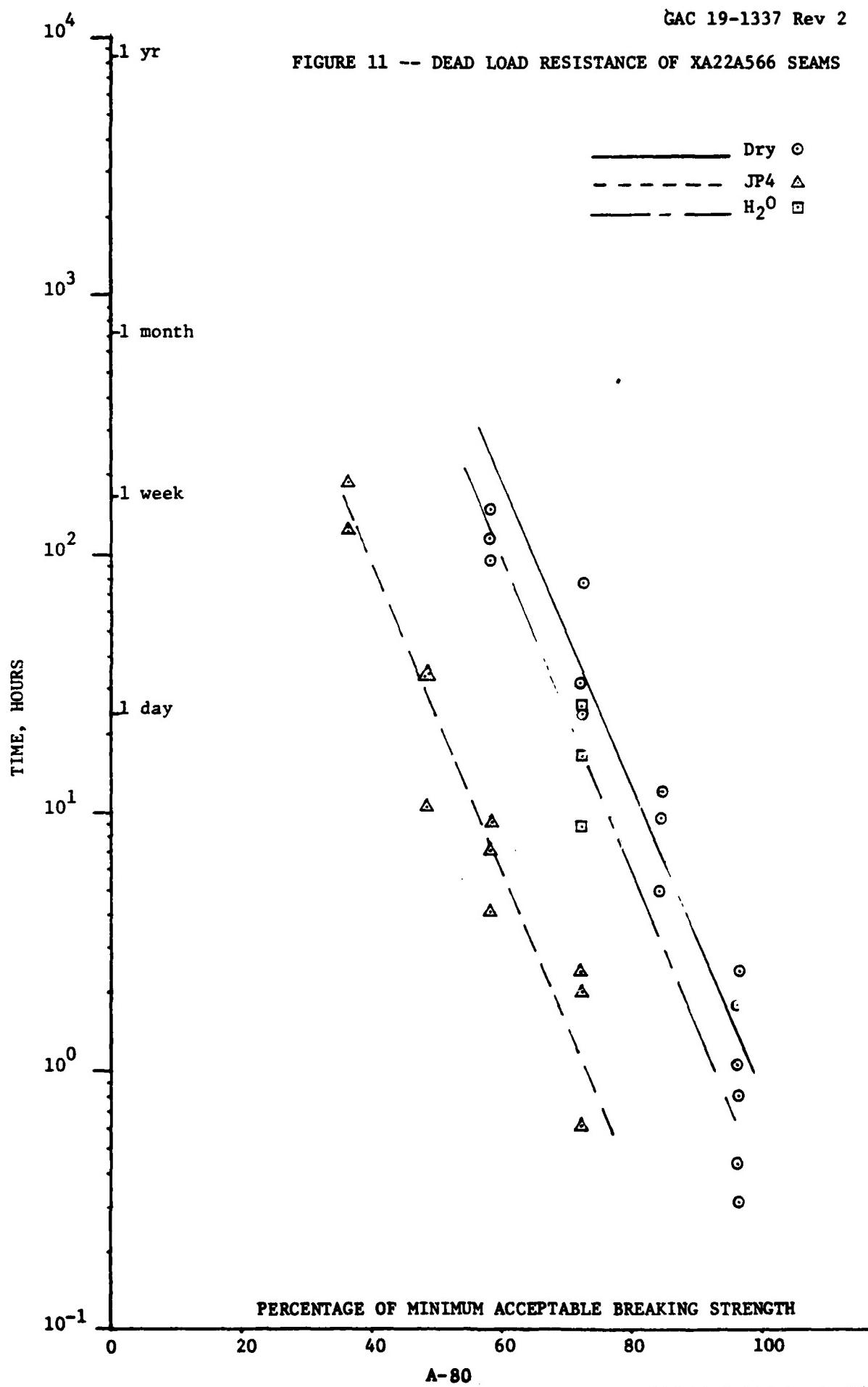
4/ Reference fuel D is ASTM D-671, a blend of 60% iso-octane and 40% toluene.

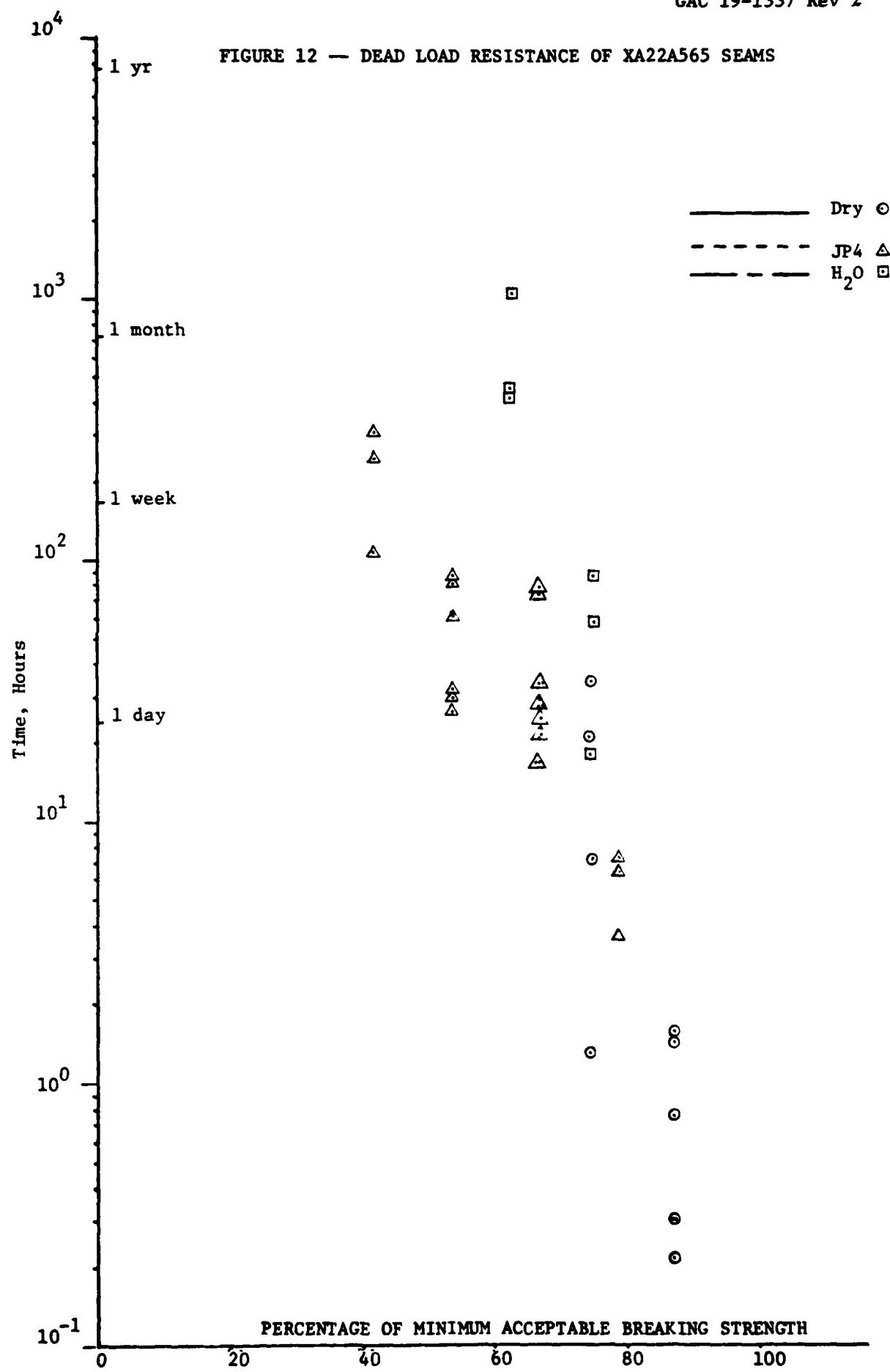
5/ After 7 days exposed at 160°F.

Data will be similar to that obtained on XA22A55.

6/ Data will be similar to that obtained on XA22A55.

FIGURE 11 -- DEAD LOAD RESISTANCE OF XA22A566 SEAMS





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Having reviewed the data and the modes of failure in the dead load study, it becomes apparent that a much broader and carefully controlled study would be required to derive a meaningful relationship between seam dead load testing and tank service life.

Therefore, the adequacy of the lap seams for these large self-supporting tanks must rest on the quick break performance which has been the specification criterion for many years.

6. Adhesion of Coated Fabric to Aluminum

Adhesion to aluminum is a function of fabric coating adhesion, the bond strength between the aluminum and the coating compound and the bond length. The adhesive system which would be used to bond the candidate coated fabrics to aluminum are the same as those used in Ref 1, and the coating compound and coating to fabric adhesive are the same as those in Ref 1. Therefore, the aluminum adhesion data generated in Ref 1 is typical of that which would be obtained with the candidate coated fabrics and is presented in Table 29.

This data shows that acceptable bonds can be made to tank fittings. The bond length required in the fitting will have to be determined after the tank configuration is selected and operating fabric stress levels have been established.

H. Trade-Off Analysis - Task 5

1. Introduction

The trade-off analysis will be based on the data generated in the previous four tasks and will be broken down into two parts. The first part will evaluate economic considerations in procuring different tank configurations versus the technical risks associated with each configuration. The tank configurations under consideration are shown in Table 30. The second part will involve assessing the operational characteristics associated with field use of the leading tank configurations as compared to existing temporary fuel storage systems. Both analyses will be based on systems for storing 21,000,000 gallons of fuel.

2. Cost/Risk Analysis

a. Tank Unit Costs

The costs of producing the tank configurations shown in Table 30 were estimated based upon using the precured nitrile coated nylon fabrication method. These costs include the hardware and accessory items included in the experimental purchase description for the prototype tank, but do not include the costs of manifolds, pumps or transfer hose that would be required in a total storage system. These costs are also based on producing tanks in unit volumes for a 21,000,000 gallon system and the numbers of units involved are shown in Table 31.

TABLE 29 -- ADHESION TO ALUMINUM

PROPERTY	FED-STD-191 A ASTM TEST METHOD	MIL-T-92123A PARAGRAPH	REQUIREMENT	ACTION DATA
Aluminum to coated fabric bond strength (initial)		4.6.16	500 lbs/in (Min)	951
Bond strength of fitting after immersion in distilled water @ 160°F +2°F for the following durations:				
14 Days	4.6.16	4.6.16	300 lbs/in (Min)	830
42 Days	4.6.16	4.6.16	200 lbs/in (Min)	786
Bond strength of fitting after fuel immersion on test fluid[] @ 160°F +2°F for the following durations:				
14 Days	4.6.16	4.6.16	400 lbs/in (Min)	521
42 Days	4.6.16	4.6.16	300 lbs/in (Min)	448
Bond load shear resistance under 50 lbs/in stress @ 200°F for 8 hours				No Slippage
Peel adhesion of aluminum strip to coated fabric (initial)		4.6.16	0.125 in. s. 11 passage (Max)	
14 Days	4.6.16	4.6.16	25 lbs/in (Min)	51.5
42 Days	4.6.16	4.6.16	47.2	
Peel adhesion of aluminum strip to coated fabric after immersion in distilled water @ 160°F +2°F for the following durations:				
14 Days	ASTM D-429 Method B	4.6.17	10 lbs/in or 40% of initial (2)	52.2 lbs/in
42 Days	ASTM D-429 Method B	4.6.17	5 lbs/in or 15% of initial (2)	(101.35)
Peel adhesion of aluminum strip to coated fabric after immersion in test fluid[] @ 160°F +2°F for the following durations:				
14 Days	ASTM D-429 Method B	4.6.17	15 lbs/in or 50% of initial (2)	25.2 lbs/in
42 Days	ASTM D-429 Method B	4.6.17	15 lbs/in or 50% of initial (2)	(53.35)
				23.8 lbs/in
				(50.35)

CONTINUED

TABLE 29 (CONT'D)

- NOTES:
- 1/ Properties after cure.
 - 2/ Whichever is greater.
 - 3/ Medium shall consist of 60% Medium No. 4, 25% Medium No. 8, and 15% Medium No. 9 per FED-STD-601, Test Method No. 6001.

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TABLE 30 -- PROPERTIES OF TANK CONFIGURATIONS UNDER CONSIDERATION

Tank Volume, Barrels	5000								
Design Factor	10	10	10	15	15	15	20	20	20
Cloth Weight, oz/sq yd	12	18	24	12	18	24	12	18	24
Flat Length, Ft	62	54	49	68	60	54	78	68	62
Flat Width, Ft	68	68	68	68	68	68	68	68	68
Flat Area, Sq Ft	4240	3700	3340	4620	4080	3700	5320	4620	4240
Fill Height, Ft	7.6	9.2	10.6	6.7	8.0	9.2	5.5	6.7	7.6
Envelope Weight, Lbs	3643	3953	4238	3970	4359	4695	4571	4936	5380
Tank Volume, Barrels	7000								
Design Factor	10	10	10	15	15	15	20	20	20
Cloth Weight, oz/sq yd	12	18	24	12	18	24	12	18	24
Flat Length, ft	85	74	67	93	81	74	107	93	85
Flat Width, ft	68	68	68	68	68	68	68	68	68
Flat Area, sq ft	5800	5060	4560	6330	5560	5060	7280	6330	5800
Fill Height, ft	7.6	9.2	10.6	6.7	8.0	9.2	5.5	6.7	7.6
Envelope Weight, lbs	4952	5406	5726	5405	5905	6420	6216	6763	7359
Tank Volume, Barrels	10,000								
Design Factor	10	10	10	15	15	15	20	20	20
Cloth Weight, oz/sq yd	12	18	24	12	18	24	12	18	24
Flat Length, ft	119	104	93	130	115	104	148	130	119
Flat Width, ft	68	68	68	68	68	68	68	68	68
Flat Area, sq ft	8120	7060	6350	8870	7820	7060	10060	8870	8160
Fill Height, ft	7.6	9.2	10.6	6.7	8.0	9.2	5.5	6.7	7.6
Envelope Weight, lbs	6933	7543	8057	7573	8355	8958	8587	9477	1030
Tank Volume, Barrels	1190				2380			3570	
Tank Volume, Gallons	50,000				100,000			150,000	
Design Factor	15				15			15	
Cloth Weight, oz/sq yd	12				12			12	
Flat Length, ft	68				68			68	
Flat Width, ft	24				40			56	
Flat Area, sq ft	1632				2720			3808	
Fill Height, ft	6.7				6.7			6.7	
Envelope Weight, lbs	1402				2337			3272	

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**TABLE 31 -- NUMBER OF TANK UNITS REQUIRED TO STORE 21,000,000
GALLONS OF FUEL VERSUS CAPACITY OF UNITS**

<u>Tank Unit Capacity, Gal.</u>	<u>Number of Units Required</u>
20,000	1050
50,000	420
100,000	210
150,000	140
210,000	100
290,000	73
420,000	50

REF: E01 380
15

b. Risk Factor

It has been assumed that technical risk is measured by the design factor used in each configuration considered. The design factor is simply the ratio of breaking strength of the fabric required in each design consideration divided by the tank envelope stress applied at each design consideration. This definition of risk does not take into consideration any degradation of tank envelope materials caused by aging or the environment, nor does it take into consideration damage to the tank which might be inadvertently caused during handling or deployment. The definition of risk does not take into consideration the increased difficulty of fabricating large heavy tanks. However, these fabrication risks are somewhat compensated for in the estimated costs for producing these units.

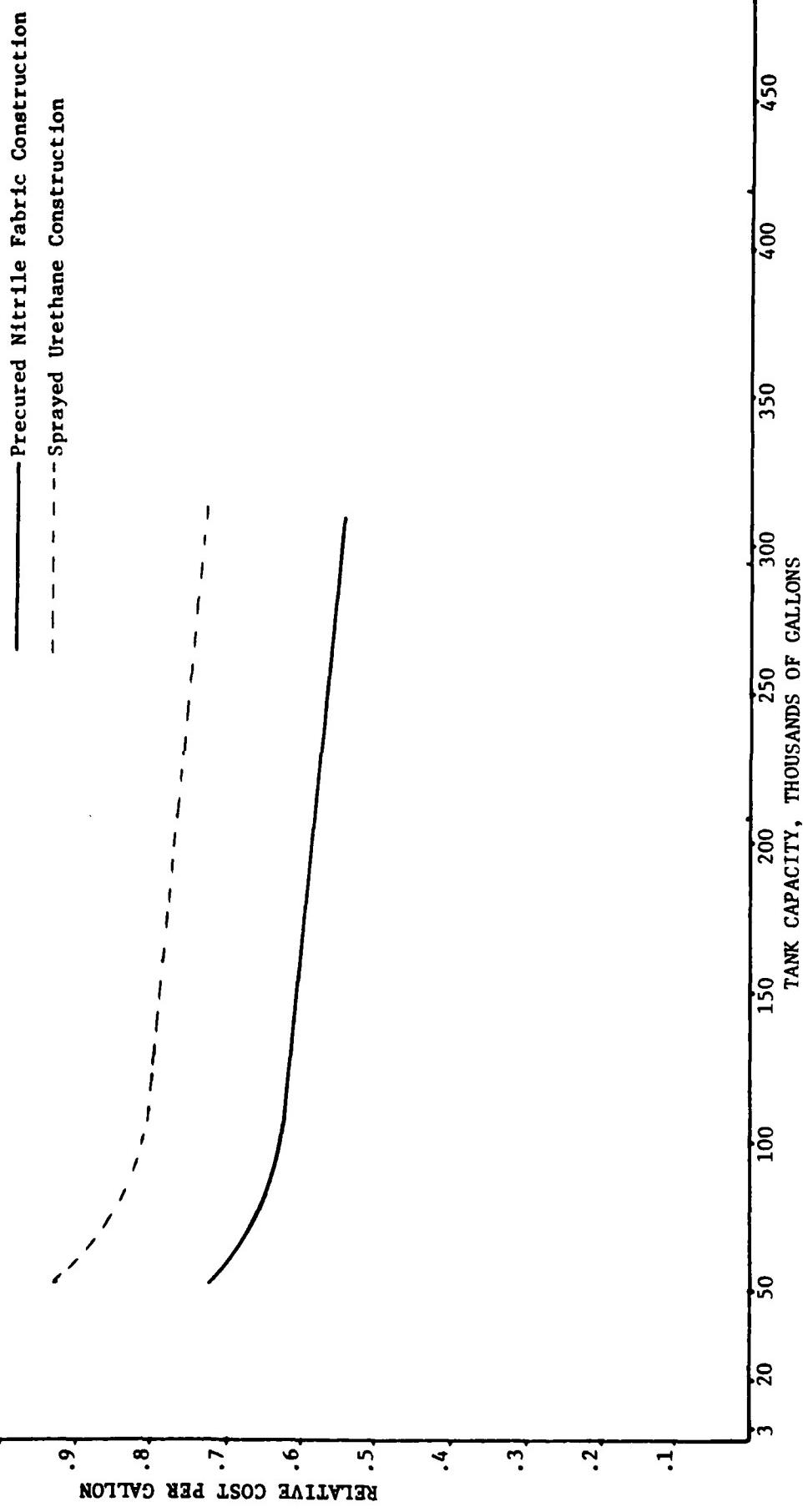
All tank costs are reported on a relative rather than an actual basis. The relative cost factors used in the figures which follow have a constant interval between scale units so the costs between different tank sizes are comparable.

c. Tank Unit Cost Versus Risk

Figure 13 shows the relative cost per gallon for storing fuel in tanks of various sizes, based on dividing the tank unit cost by its capacity, versus tank size. The data is plotted for a constant design factor of 15, i.e., constant technical risk. This figure shows that the per-gallon cost for storing fuel decreases fairly rapidly as tank size increases up to approximately 100,000 gallons, after which it decreases slowly and constantly. This data indicates that there would be a significant cost savings to the Army if 100,000 gallon tanks are selected, with some smaller additional savings available if larger tanks are selected, based strictly on the purchase price of the units.

The dotted line in Figure 13 shows the rough order of magnitude costs for producing tanks by the polyurethane spray process. Costs for producing tanks by this method are significantly more expensive than those for producing tanks in a seam press using pre-cured nitrile coated fabric and, therefore, will be eliminated from further consideration for this reason.

FIGURE 13 -- RELATIVE TANK UNIT COST PER GALLON FOR A 21,000,000 GALLON
STORAGE SYSTEM VERSUS TANK CAPACITY
(DOES NOT INCLUDE DEPLOYMENT COSTS)



d. Storage and Deployment Efficiency

The primary objectives of this project are to minimize the weight of large collapsible tanks and the ground area required for storing large volumes of fuel. Therefore, relative tank costs were plotted as a function of tank area and tank envelope weight using three coated fabric weights and three design factors as shown in Figures 14 and 15.

A comparison of the data in these two figures shows that for a given tank size and design factor the configuration with the lowest weight would be one using 12 oz/sq yd cloth while the one with lowest ground area would use 24 oz/sq yd cloth, again showing that the requirements of minimizing weight and area are mutually incompatible. The best configuration would be the one which has the best combination of weight and area. If it is assumed that minimum weight and minimum area are equally important, then the configuration which had the lowest sum of envelope weight and ground area would be the best configuration.

Figure 16 shows the relative cost of each configuration as a function of the sum of envelope weight and ground area. This figure shows that the cost of tanks is relatively independent of the weight of coated fabric used at a particular design factor and tank volume. The reason for this is that as tank head is increased to reduce ground area, heavier fabric must be used for the higher operating stresses which increases tank weight. So the benefit gained in reducing area is offset in large measure by the increased weight of the tank. Similarly, the tank made using heavier fabric will require less labor to produce because the area of fabric to be handled is less, but the increased cost of the heavier material offsets the savings in labor.

Figures 14 thru 16 also show that tank costs are not significantly reduced by selecting configurations having smaller design factors. Using the 7000 barrel tank as an example, reducing the design factor from 15 to 10 increases the technical risk by 33% while only reducing the tank cost by 11% and the weight plus area factor by 9%. A similar argument

FIGURE 14 -- RELATIVE TANK COST VERSUS FLAT AREA OF CANDIDATE CONFIGURATIONS

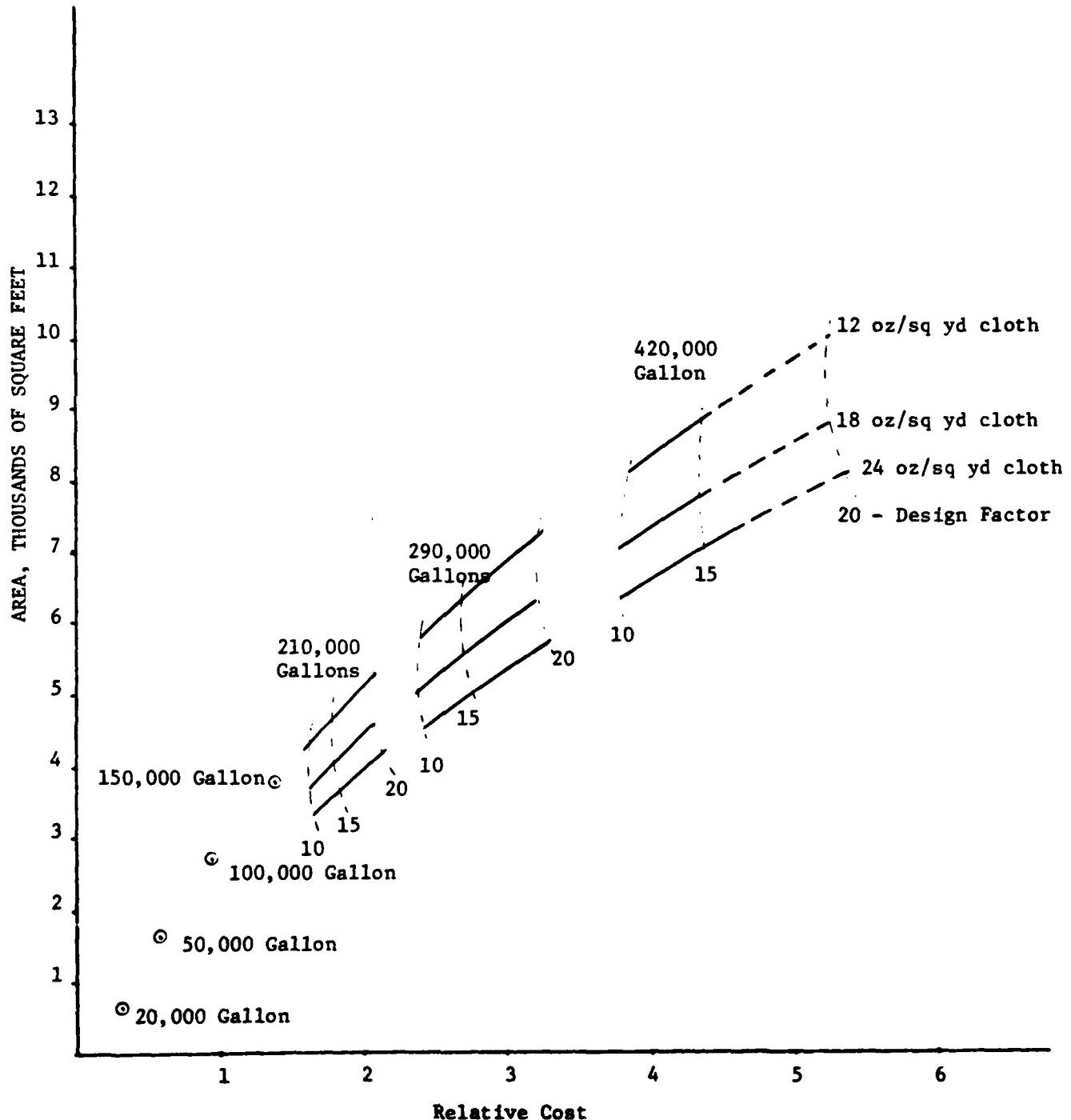
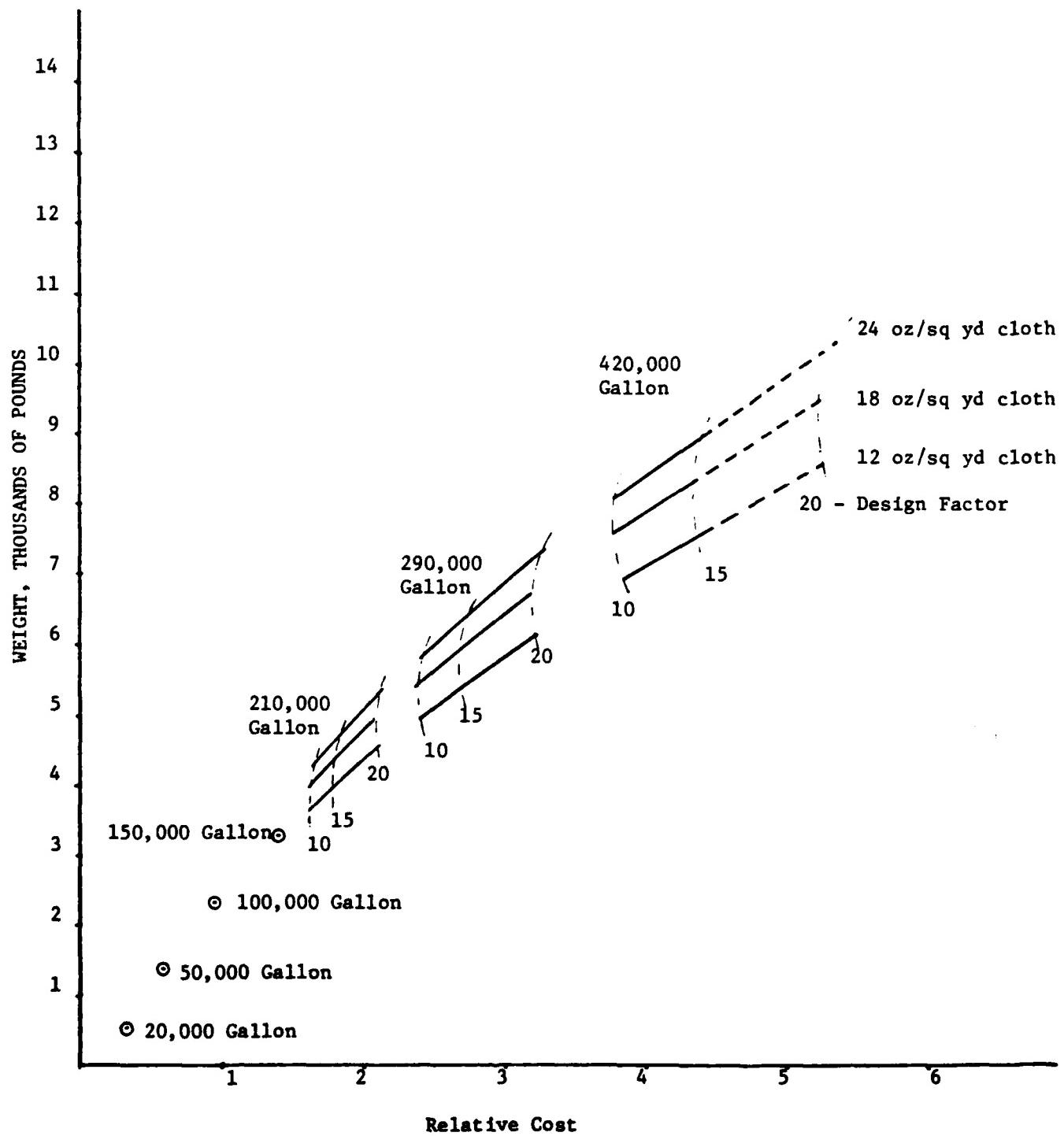
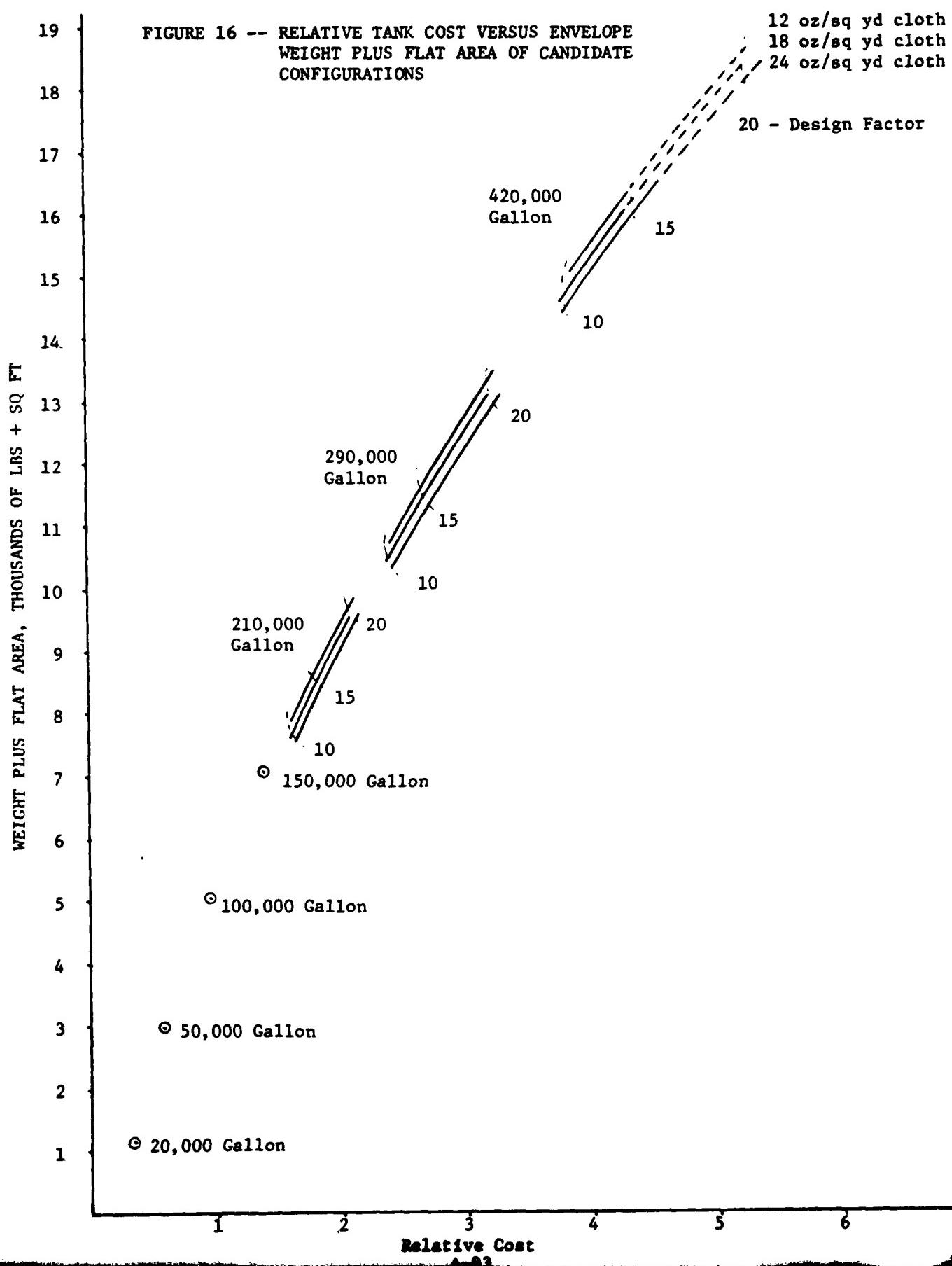


FIGURE 15 -- RELATIVE TANK COST VERSUS ENVELOPE WEIGHT OF CANDIDATE CONFIGURATIONS

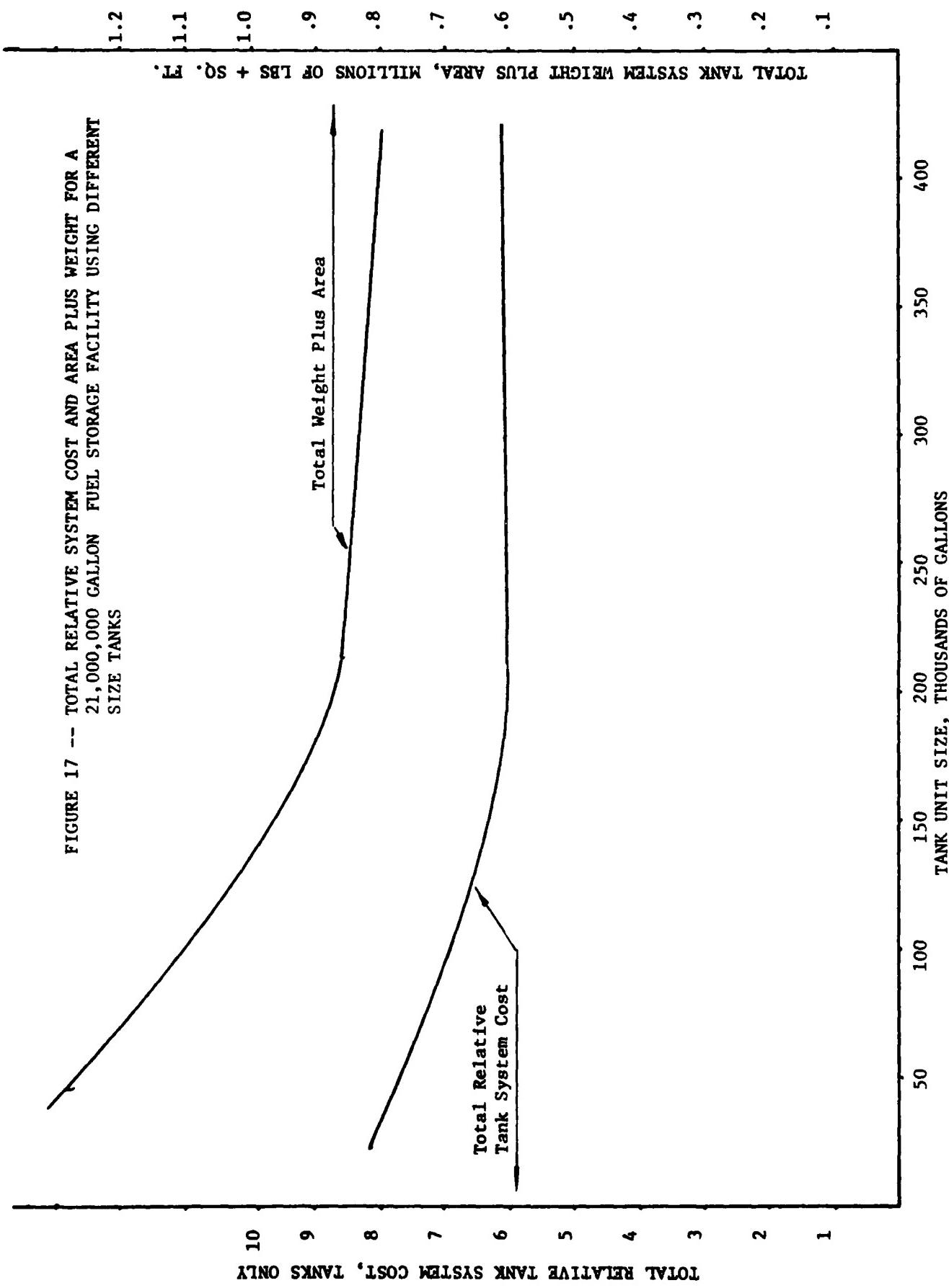




can be developed for the other tank sizes under consideration. It doesn't seem as though the weight, area, and cost savings obtained in reducing the design factor are worth the additional risk unless the Army is willing to pay a high premium for weight and area reduction. Please note that some of the data shown in this figure was developed for configurations outside the design constraints of maximum weight, width and length, in order to develop profiles of cost and risk. Those configurations outside of these constraints are shown as dashed lines. Also note that the data points shown for 20,000; 50,000; 100,000; and 150,000 gallon tanks are for units manufactured using 12 oz/sq yd cloth and with a design factor of 15.

In analyzing the economics of a fuel system, the total purchase cost of tank units must be considered. Figure 17 shows the total relative system cost based on the number of units of each tank size required to store 21,000,000 gallons of fuel as shown in Table 31. All of the configurations are based on a design factor of 15. The total tank envelope weight plus ground area are also plotted in this figure. The data in this figure shows that total tank cost and area plus weight decrease fairly rapidly as unit tank sizes increase to 210,000 gallons (5000 barrels). As larger tanks are used, the total system cost increases slightly and the area plus weight decrease slightly. This data indicates that based on the costs of tank assemblies and their weight and ground area, and not considering the costs of deploying the system and providing hook up accessories, the optimum tank size is 210,000 gallons.

FIGURE 17 -- TOTAL RELATIVE SYSTEM COST AND AREA PLUS WEIGHT FOR A
21,000,000 GALLON FUEL STORAGE FACILITY USING DIFFERENT
SIZE TANKS



3. Analysis of the Operational Characteristics of Large Collapsible, Self-Supporting Tanks

a. Introduction

This analysis involves a comparison of the operational characteristics of various sized self-supporting fabric tanks used to form 21,000,000 gallon fuel storage systems.

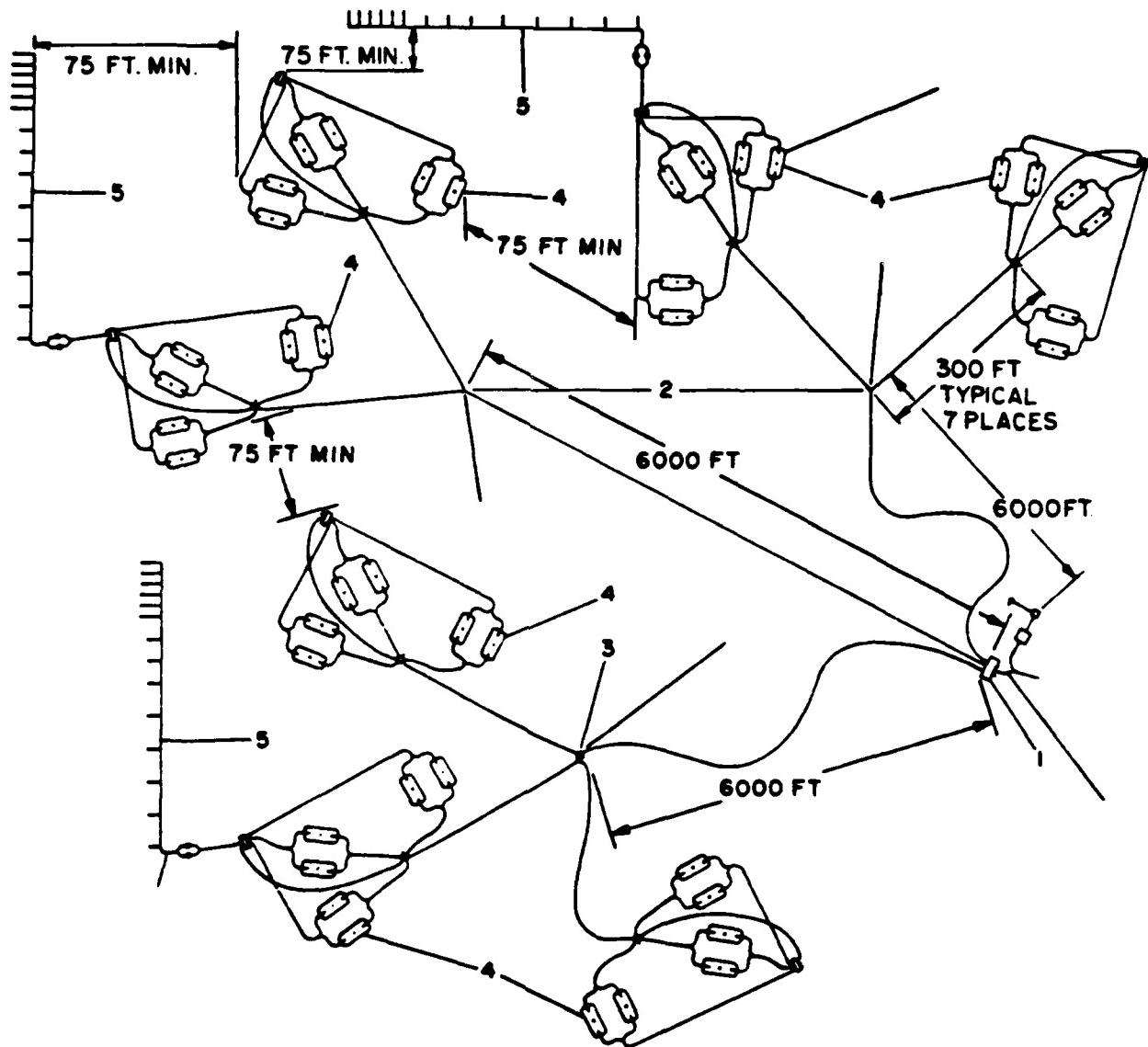
Fabric tank sizes from 50,000 to 420,000 gallons were considered, but the bulk of the analysis concentrated on the 210,000 gallon tank since it appears to be the most cost effective size. This analysis deals primarily with the ease of assembly and installation effort required in deploying each of these systems since the primary objective of this project is to develop a rapidly deployable collapsible fabric tank. Cost effectiveness characteristics were discussed in the cost/risk analysis in the preceding section. Other operational characteristics were also considered. Data present in References 19 through 22 was used to aid in conducting this study.

b. Deployment Analysis

The deployment analysis involves comparing the number of tank units required in a 21,000,000 gallon storage system, the number of hoses and fittings required, the combined weights of system components which must be handled, site preparation, and the effort and equipment required for system installation and assembly.

(1) System Components Requirements and Weights

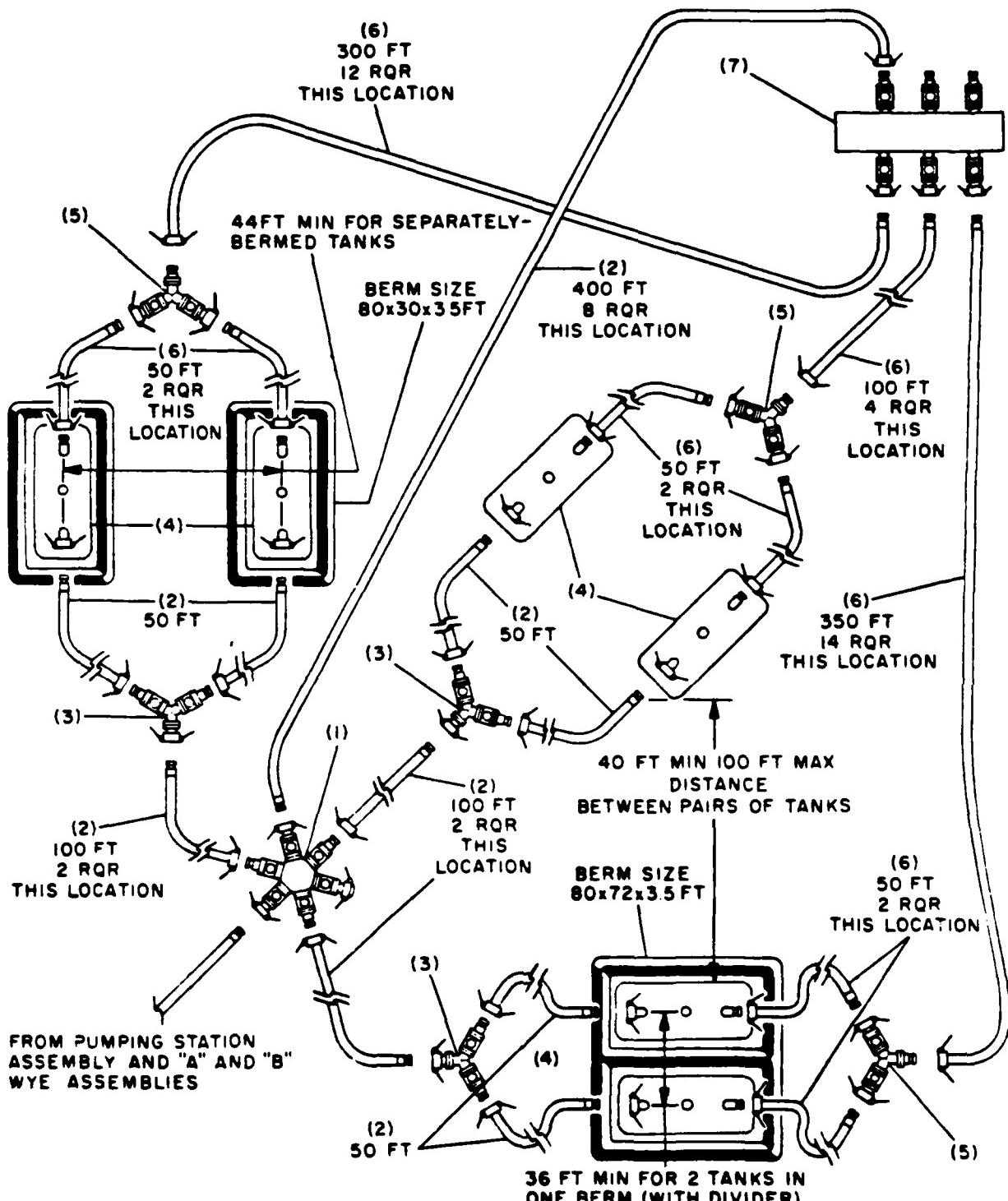
The Tactical Marine Terminal (TMT - Reference 19) was used as a baseline in comparing the number of components required for storing 21,000,000 gallons of fuel in systems composed of each of the different size tanks (see Figures 18 and 19). The components required in each system, their numbers, weights and volumes are presented in Table 32. The results indicate that using larger tanks



1. Pumping station assembly
2. Hoseline distribution assembly - "A"
(2 rqr)

3. Hoseline distribution assembly - "B"
4. Fuel tank module assembly (7 rqr)
5. Fuel dispensing assembly (3 rqr)

FIGURE 18 -- LAYOUT OF TACTICAL MARINE TERMINAL SITE



1. Manifold assembly
2. Discharge hose assembly, 6 inch by 50 foot (20 rqr)
3. Flanged wye assembly (3 rqr) (MFC81718-P/N667F-6)
4. Collapsible 50,000 gallon tank (6 rqr)
5. Flanged wye assembly (3 rqr) (MFC81718-P/N667F-6)
6. Suction hose assembly, 6 inch by 25 foot (42 rqr)
7. Unit 604A Diesel Engine Driven 600 gpm pump assembly

FIGURE 19 -- TANK LAYOUT IN TMT MODULE

TABLE 32 -- SYSTEM COMPONENTS, NUMBERS, WEIGHTS AND VOLUMES FOR 21,000,000 GALLON
FUEL SYSTEMS USING DIFFERENT SIZE FUEL TANKS

Cloth Weight Tank Size Components	No.	50,000 Gals Wt., Lbs Vol., CuFt	100,000 Gals Wt., Lbs Vol., CuFt	150,000 Gals Wt., Lbs Vol., CuFt	5,000 Barrels Wt., Lbs Vol., CuFt	7,000 Barrels Wt., Lbs Vol., CuFt	No.	10,000 Barrels Wt., Lbs Vol., CuFt
1. Tanks	420	68,000 (1)	210	500,000 (1)	140	440,000 (1)	100	420,000 (1)
2. Crates	420	300,000 120,000	210	200,000 80,000	140	190,000 75,000	100	170,000 70,000
3. Inlet/Outlets	840	(2)	(1)	420 (2)	(1)	280 (2)	(1)	200 (2)
4. Vent/Drain	420	(2)	(1)	210 (2)	(1)	140 (2)	(1)	100 (2)
5. Manifolds Assm	70	TBD	TBD	TBD	TBD	TBD	TBD	TBD
6. Wye Assembly	420	TBD	TBD	0	0	0	0	0
7. Hoses								
a. 60x25ft (suct)	2940	TBD	2100	TBD	1400	TBD	TBD	490
b. 60x50ft (dis)	1400	TBD	TBD	1190	TBD	TBD	TBD	350
c. 60 lines to ship terminal 60x6000ft	30	TBD	TBD	30	TBD	TBD	TBD	175
8. Pumps (600 gpm)	70	TBD	TBD	70	TBD	TBD	TBD	30
9. Pumping Stations	10	TBD	TBD	TBD	10	TBD	TBD	10
10. Dispensing Assy's	30	TBD	TBD	TBD	30	TBD	TBD	30

(1) Included in crate volume
(2) Included in tank weight

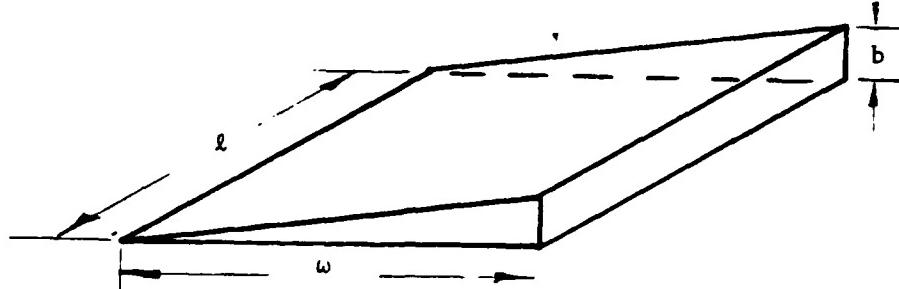
results in systems with fewer component parts required for system assembly. In comparing a system composed of 50,000 gallon tanks versus 210,000 gallon tanks, one fourth as many tanks, 3290 less suction and discharge hoses, 20 less manifolds, and 420 less wye assemblies would be required in the system composed of 210,000 gallon tanks. This is a considerable reduction in the number of parts required for the fuel system. The number of pumps remains essentially the same for the same overall pumping capacity and the long delivery hoses between the pumping station and the tank field are assumed to remain the same. One pumping station was arbitrarily assumed for each 2,100,000 gallons of system capacity.

The weights and volumes of the self-supporting, flexible tanks and crates for the system are similar for tank sizes larger than 50,000 gallons.

(2) Site Selection and Preparation

Site selection involves locating accessable ground areas free of sharp objects which are as flat and level as possible. Using larger tanks involves locating fewer sites but they must be larger and level over a greater area. Site selection also must consider site preparation requirements for the larger tanks. For instance, 1/4 as many sites are required for the 210,000 gallon tanks as for the 50,000 gallon tanks, but the 210,000 gallon tanks each require more than 3 times the area.

The slope of the selected sites is important for the volume of material to be removed is a function of the site width squared if constant ground slopes are considered.



$$V = l \times 1/2 bw \quad \text{Where: } l = \text{constant}$$

b = maximum depth, $f(w)$ for constant slope

w = width

Since only one-sixth as many sites need to be selected, the average ground slope of the sites should be less than the average slope for 6 times as many sites. Thus, the volume of material to be removed should be similar for all of the collapsible, self-supporting tank systems although the depth removed on one side of the site will be several times greater for the larger tanks. There is a probability of uncovering more underground obstructions at the greater depths required for large tanks that might require their abandonment compared to more sites at lesser depth required for smaller tanks.

Site preparation includes leveling the ground at the site, removing sharp debris, constructing the berm and installing the drains. Machinery, such as bull-dozers, graders and front-end loaders are required for this task. Manpower is required for final grooming. The total ground leveling required for the self-supporting flexible tanks appear similar for each system. Total effort required to construct the berms of each system, however, decrease as tank size increases. For instance, twice the volume of fuel can be contained by doubling the ground area either by doubling the length of the berms in the length direction or in the tank width direction, or by increasing both berms some smaller amount. Thus, the total berm length per gallon will decrease

with tank size. A trade-off with berm height is also possible, however, the volume of earth per foot of berm increases with the square of berm height if the width of the berm remains proportional to its height. Efforts for installing the berm drains decreases as the tank sizes increase because the number of tanks in the system decreases. It appears that the site preparation effort required for self-supporting collapsible tanks decreases as the size of the tanks increases, but only slightly so.

No particular tank size appears to offer any significant advantage toward rapid deployment of a 21,000,000 gallon fueling system based on site selection or preparation considerations.

(3) Tank Installation

Tank placement for the system includes transporting the self-supporting flexible tanks to the site, placing them in the proper position, unrolling them from their mandrels (larger sizes) and unfolding them. The larger tanks will be packaged on a mandrel so a crane or a pair of fork-lift vehicles supporting the mandrel can be backed through the site area while unrolling the tank from the mandrel. Manpower is then used to unfold the outer 1/4 or 1/3 portions of the tank. The placement of the packaged tank on the mandrel is such that the drains of the one end are in the first portion of the tank being unrolled. Unrolling is started at the lowest end of the site. The bottom of the tank is located on the outside of the roll so the bottom center of tank will be placed in position and doesn't need to be handled a second time.

Tank installation effort and the amount of mechanical assistance required for installation of tank units increases as tank size increases, but there are a fewer number of large units required in a storage system. In a 21,000,000 gallon system, 420-50,000 gallon or 100-210,000 gallon tanks would be required which means

that 4.2 times more effort could be expended in positioning a 210,000 gallon tank than a 50,000 gallon unit for the installation of either system to require the same total effort. Therefore, it appears that system installation effort would be reduced if larger tanks are used provided that proper equipment is available to aid in the installation effort.

(4) Tank System Assembly

After tank placement, suction or discharge hoses are connected to the tank fittings and the manifolds and pumps are interconnected. The number of lengths of suction and discharge hose decreases with tank size. For example, going from 50,000 to 100,000 gallon tank sizes, allows the elimination of the flanged wye assemblies connecting two 50,000 gallon tanks together and eliminates one-half of the number of suction and discharge hoses used between the two tanks. The number of vent/drains are also reduced to 1/2 the number used for 50,000 gallon tanks making up a 21,000,000 gallon system. The number of manifolds would remain the same until the size of the tanks reach 5,000 barrels. The number of connections required for the Hasty Storage Reservoirs and the steel bolted tanks should be similar to those listed for the largest self-supporting flexible tank systems.

The number of pumping stations was arbitrarily assumed to be one station for each 2,100,000 gallons of fuel storage capacity. There are three (3) 6000 feet long hoses required for each of the 10 stations. A reduction in the number of pumping stations would significantly reduce the amount of hose required.

The number of fuel dispensing assemblies required was assumed to be 30 which corresponds to 900,000 gallons per assembly for one fuel type and 600,000 gallons for each of two other fuel types.

(5) Deployment Analysis Summary

From the above discussions it appears that large self-supporting tanks offer the advantage of reducing the effort required to prepare berms and significantly reduce the effort required for assembly of the storage system because of the fewer number of component parts required as compared to smaller collapsible tanks. However, the larger tanks will require more mechanical assistance for rapid deployment due to their increased bulk and weight. Large self-supporting fabric tanks also appear to offer significant advantages over the Hasty Storage Reservoir and the steel bolted tanks because they require less effort for deployment.

c. Analysis Of Other Operational Characteristics

(1) Reliability

An analysis of the reliability of a fuel storage system must consider the reliability of each component and the number of components in the system. The use of larger storage tanks reduces the number of tank, hose and interconnecting hardware components required which, therefore, improves the reliability of the system providing that the reliability of individual units is constant. The reliability of all tanks under consideration should be similar since all were designed with the same design factors and use the same basic materials and fabrication technique.

However, the reliability of tanks may decrease slightly as size increases because larger units have more fabric and total seam length than smaller ones. Therefore, system reliability should be relatively independent of tank size.

(2) Maintainability

Maintainability involves inspection of tank systems and the degree of difficulty involved with repair or replacement of components. The inspection effort required for systems of small or large

collapsible tanks will probably be approximately the same. There are fewer large tanks to inspect in a system, but each will have a greater area of fabric to inspect and their filled height will be higher making inspection more difficult. Repair of larger tanks will be more difficult because the units are larger and heavier. It will take longer to empty them to make a repair and they will be more difficult to handle in making a repair because of their weight. Replacement will also be more difficult because of their weight and physical dimensions.

(3) Vulnerability

It is difficult to assess the differences in vulnerability between the different fuel storage systems under consideration. Even though larger tanks will be made from materials having higher tear strengths than smaller units, they will be operating at higher envelope stress levels. Therefore, they probably will have the same tear propagation properties as smaller units. More fuel will be lost if a large unit ruptures due to accidental damage or enemy action than would be lost from a smaller unit. However, many more smaller units are required in the fuel storage system making them statistically more vulnerable to damage.

(4) Personnel Safety

Personnel safety is related to protecting the operating personnel and those located nearby. Safety signs and barriers are approaches to warn or prevent personnel from bringing ignition sources in the area. Earthen berms are located around all the tanks to contain the fuel, if a tank is ruptured. The location of a fuel system is normally chosen so that if the system sustains major damage, the fuel doesn't run into troop areas.

From these approaches, safety doesn't appear to be related to tank size for the same size capacity fuel system. The tallest self-supporting tank heights may require extra high berms to contain

the fuel when a tank is ruptured because the potential energy in the fuel is the greatest and it is converted into kinetic energy upon rupture.

(5) Human Factors

Human factors are related to the environment that the man works in and the ease with which he can do his assigned tasks in this environment with normal strengths, dexterities, and motor skills using common tools or equipment. Since the tank system must be capable of being deployed and operated over a broad range of environmental conditions, the man also must be able to do his tasks under the same range of environmental conditions. All of the self-supporting flexible tanks come as one integral assembly containing the inlets/outlets, drains, and hand holds for aiding deployment. Thus, system assembly is at a module level.

(6) Integrated Logistic Support

Integrated logistic support involves the coordination of parts and equipment required to install and maintain the fuel storage system. This involves training personnel to install and assemble the system, and providing equipment required to properly install and maintain the system.

The effort required to train personnel to deploy and maintain a fuel storage system appears to be independent of tank size. The training required for site preparation, tank deployment and maintenance will be virtually the same for any size tank even though the dimensions, weights and number of units required in a given system will change. The training effort per man was found to be approximately one training hour per man for a 210,000 gallon tank, Reference 21.

Larger tanks will require equipment capable of handling greater bulk and weight. More machine hours will be required in deploying or replacing a large tank unit, but fewer large units are

required in a given system. All systems under consideration are capable of being transported by normally available military vehicles. All but the largest tanks can be packed in 8 x 8 x 25 ft crates weighing less than 10,000 pounds where normal railcar, highway or marine vehicles can be used to transport the systems using normal infrastructure. Delivery to the installation site and tank deployment will require all terrain vehicles like fork lifts, trucks or mobile cranes. These vehicles would also be required for tank replacement.

(7) Nuclear Effects

Effects of nuclear weapons is a special case and is related to the thermal and pressure capabilities of the tank structure, hoses, pumps and other components of the system. The tanks being free standing and flexible can take over-pressures many times their normal operating pressures. For instance, design operating pressures result in normal operating fabric stress levels of 40 to 60 pounds per inch, while the fabric has an initial quick break strength of 600 to 900 pounds per inch. The thermal capability of the tank fabric is a function of coating weight and its heat transfer characteristics. Rubbers ablate at very high heating rates which will protect the cloth for short periods of exposure at large heating rates so the tanks should have survival characteristics similar to the other parts of the system. Tanks designed to the greater fill heights will have a slightly greater resistance to nuclear effects because they have thicker elastomer coatings on the fabric. The effect of nuclear weapons on the Hasty Storage Reservoirs is expected to be more severe because of their lighter construction. However, since they are supported by an earthen berm, their bottoms and sides may be protected from thermal effects.

SECTION III -- CONCLUSIONS

The state-of-the-art analysis has shown that it is technically feasible to produce a 7000 barrel, rapidly deployable, collapsible fabric, fuel storage container within the weight, length and width constraints set forth in the project using nitrile elastomer coated fabric made from 12 oz/sq yd basket weave nylon cloth. The goals of the project were to minimize ground area and tank weight which were found to be mutually incompatible requirements. The tank can be manufactured from coated fabric made using 18 oz/sq yd cloth to reduce ground area, but the tank would be heavier than one made with 12 oz/sq yd cloth, and the heavier coated fabric will not meet cold temperature requirements. Tank area could be further reduced using 24 oz/sq yd cloth as the reinforcing material, again at the expense of additional tank weight, but this material would not meet either the fuel diffusion or the cold temperature requirement. It is felt that minor adjustments in fabric processing procedures will produce a coated fabric made from 24 oz/sq yd nylon which will meet the diffusion requirement, but that different coating compounds will be required to meet cold temperature requirements for these heavier fabrics unless the cold temperature requirement is relaxed.

The study also showed that acceptable tanks can be manufactured using either the precured nitrile coated fabric process or the polyurethane spray process. The polyurethane coating compounds used in the spray process have slightly better physical properties than nitrile elastomers, but are significantly more expensive. Also, the special requirements of a production facility for a product this large using the spray process would add significantly to the cost of units produced by this method. Tanks made from cloths coated with thermoplastic urethane were judged unacceptable because of plastic flow properties which could affect long term integrity of seams.

An analysis of reinforcing cloths showed that basket weave nylon materials are state-of-the-art. Aramid cloths offer the advantage of reducing the weight of large tanks by approximately 40%, but their cost is high and GAC's testing of currently available adhesive systems for bonding elastomers to them indicate that they degrade when exposed to fuel and water. Aramids are also high modulus materials which may be damaged at creases when tanks are folded for storage and shipment. If light weight tanks are desirable, the Army should consider continuing the investigation of aramid reinforcing materials and the development of an aramid coated fabric construction for collapsible storage tanks.

An economic analysis of collapsible tanks showed that tanks larger than 100,000 gallons will reduce the storage cost of fuel per gallon of tank capacity. When a 21,000,000 gallon fuel storage system was analyzed, it was found that 5000 barrel containers would minimize total system tank cost. The use of tanks larger than 5000 barrels reduced the total weight and ground area of tanks in the system only slightly, but the total tank cost also increased. The trade-off analysis showed that large collapsible tanks significantly reduced deployment effort as compared to the Tactical Marine Terminal, the Hasty Storage System, or the Bolted Steel Storage Tank. The 5000 barrel container appears to be the optimum size container based on these economic considerations and system rapid deployment requirements. Please note, however, that the economic considerations are based on a 21,000,000 gallon system involving 100 tanks of 5000-barrel capacity (see Table 31). If a smaller storage facility is finally selected the 5000 barrel tanks may not be most economical because fewer units would be procured which will increase the price per unit. The use of a smaller storage facility may favor using a smaller tank.

Collapsible fabric tanks have historically been designed using design factors of 15 or better, and physical properties generated on candidate materials indicate that a design factor of 15 should be used in the BFTA. Dead load seam data indicates that seams should not be subjected to more than 33% of their quick break strength which represents a design factor of 3. Many tank specifications allow a

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reduction in physical properties after fuel or water immersion to 40% of original which represents a design factor of 2.5. If a factor of 2 is applied for uncontrollable variables like undetectable defects in the reinforcing fabric, the combined design factor becomes 15. Therefore, the design factor of 15 is appropriate for large tanks. Seam dead load tests in fuel and water should be continued to substantiate the design factors required in designing the tank.

SECTION IV -- RECOMMENDATIONS

It is recommended that a 5000 barrel prototype tank be manufactured by the pre-cured nitrile coated fabric process in a seam press using 12 oz/sq yd basket weave nylon as the reinforcing material. This tank will have flat dimensions of 68' x 68' and will be 6.7' high when filled based on a design factor of 15. Envelope loads are such that 2" wide seams will be used between body patterns and standard tank fittings can be used. This tank should be subjected to the quality assurance tests identified in the experimental purchase description for the Bulk Fuel Tank Assembly (BFTA) following which it should be subjected to field handling and deployment studies by the Army, including long term stand test and cyclic loading and unloading with fuel, to determine the economic and logistic benefits of the BFTA over existing temporary fuel storage systems.

If the BFTA concept is proven advantageous, additional consideration should be given to development of an aramid reinforced tank construction. Use of aramid would reduce tank weights by approximately 40% and improve the speed with which tank systems can be deployed and assembled providing coating adhesion can be improved and the aramid is not degraded at fold lines during packaging, storage and deployment.

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APPENDIX B

TEST REQUIREMENTS & PROCEDURES

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3. REQUIREMENTS

3.3 Description. The assembled pillow-type tanks shall consist of elastomeric-coated fabric with attached handles; filler discharge assemblies with access doors; a vent fitting with pressure relief valve; and a water drain fitting. The tanks shall be furnished complete with accessories and emergency repair items as specified herein.

3.2 Tank Performance. Tanks and components shall: withstand folded storage at ambient temperatures from minus 30⁰F to plus 160⁰F; be capable of operational use (being handled, unpacked, unrolled or unfolded, storing fuel, rolled, folded, and packed) at ambient temperatures from minus 25⁰F to plus 125⁰F. The tanks shall not be damaged when exposed to fungus growth or relative humidity up to 100 percent such as is encountered in tropical climates. The tanks shall be suitable for use in continuous contact with rain water, ground water, salt water, or water associated with fuels. The tanks shall be suitable for continuous storage of fuel for a period of up to one year. There shall be no evidence of leakage or seepage when the tanks are filled to their maximum height with diesel fuel, jet fuel, aviation or motor gasoline containing a maximum of 40% aromatics. The tanks shall have a minimum over capacity of 10 percent without rupture or evidence of weakened areas and without leakage or seepage of fuel.

3.3 Materials. Materials shall be as specified herein. Materials not specified shall be selected by the supplier and shall be subject to all provisions of this specification. Tanks may not be made with materials that fail to meet the requirements of Tables I through V; however, conformance with these requirements shall not be construed as justification for failure to meet other performance requirements of this specification.

3.3.1 Fabric. The fabric used in the tank construction shall conform to the requirements of Table I. Fabric shall be free from the following defects:

- (a) Any hole, cut or tear
- (b) Weaving imperfections such as loose threads or slubs.
- (c) Abrasion marks (damaged yarns; displaced weave).
- (d) Chronic wrinkles or folds that effect coating.
- (e) Oily spots that effect coating

3.3.2 Coating compounds. Each elastomeric compound applied to the fabric including the tie gums, jump coats, diffusion barrier (if used) shall conform to the requirements of Table II.

3.3.3 Coated fabric. The cured coated fabric shall be free from blisters, pinholes, or signs of coating delamination. The cured coated fabric shall conform to the requirements of Table III. Color shall be optional.

3.3.4 Aluminum alloys of tank fittings. Wrought aluminum shall conform to the applicable alloy designations in accordance with Standards for Aluminum Mill Products. Cast aluminum alloy shall conform to QQ-A-591, alloys A13, A360, or 217 for die castings; QQ-A-596, class 8, for permanent and semi-permanent mold castings; or QQ-A-601, or QQ-A-691, alloy 596, T6, or alloy 40E, T5 for sand castings.

3.4 Construction The tanks shall be fabricated from elastomeric coated fabric. End closures, if used, shall be vulcanized and subject to all requirements of seams (see 3.4.1). The location of the fittings shall be as shown in Figure 1. A diffusion barrier may be incorporated into the composite coated fabric to limit the fuel diffusion rate through the tank wall. If used, the barrier shall meet the requirements of Table II. Bonds between the barrier and coatings shall conform to the requirements of Table III with respect to coating adhesion initially and after fuel and water immersions.

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3.4.1 Tank Seams. All tanks seams, including seams between tank body and coated fabric rings of fittings flange attachments, handle patches, reinforcing patches and factory repairs shall conform to the requirements of Table IV. Exposed cloth of the composite coated fabric along the edges of all of these seams shall be covered with a protective strip of gum or coated fabric which shall be not less than 0.75 inch wide and not less than 10.0 mils thick after cure. The protective strip shall be of the same compound as or shall satisfy all requirements for the coating compound to which it is bonded. Its bond to the tank and seam compound shall meet the requirements of Table III. No seam, splice, chafing patch or molded fitting flange of the tank shall intersect any other seam.

3.4.2 Handles. Handles shall be bonded to the tank at 12 foot intervals as shown in Figure 1. The handles shall be U-shaped straps fabricated from nylon webbing or cloth and fastened to a coated fabric patch similar to the tank body material. The two ends of each strap shall be attached to each patch at points 12 inches plus or minus 1 inch apart. The length of the strap between the two points of attachment shall be 16 inches plus or minus 1 inch. The patch and strap assembly shall be bonded to the bottom of the tank just below the peripheral fold line. The bonds between each handle patch assembly and the tank fabric shall be capable of withstanding perpendicular loads of 1,000 pounds.

3.4.3 Chafing patches. The interior and exterior of the tank, opposite the location of each fitting shall be provided with bonded coated fabric chafing patches as shown in Figure 1. The chafing patches shall be made of the same coated fabric used to fabricate the tank.

3.4.4 Fittings. The tank shall be furnished with the following fitting assemblies located as shown in Figure 1: The filler discharge assembly, the drain fitting assembly, and the vent fitting assembly.

The pressure relief cap of the vent assembly shall open when subjected to an internal pressure of 3 inches of water. The design of all cam-locking type, quick-disconnect couplings shall conform to MS27019. The supplier shall furnish compression fitting components for that portion of the tank hardware which is bonded to the coated fabric of the tank wall, provided that the design conforms to the bond requirements of Table V and that complete design drawings for the fittings are approved by the U S Army Mobility Equipment Research and Development Command, Ft Belvoir, Virginia 22060. The minimum access dimensions to the tank shall be an oval 10 inches by 16 inches.

3.4.4.1 Protective coatings. Aluminum alloy tank fittings shall have protective coatings as specified in Figure 1. All parts exposed to view on the outside of the tank shall be anodized to MIL-A-8625. Alodine (chemical conversion) coatings shall conform to MIL-C-5541.

3.5 Accessories. Unless otherwise specified each tank shall be provided with the following accessories:

- (a) "A commercial fuel resistant non-collapsible hose assembly", size as appropriate for intended use to fit drain fitting (Fig.1) attached to a positive shutoff valve. The hose shall be furnished without static wire.
- (b) Two 10-foot-length hose assemblies conforming to MIL-H-370, Type II, size 10 (6 inch), class 1, style A.
- (c) One 6-inch gate valve or ball valve with quick disconnect couplings male one end, female opposite end.

3.6 Emergency repair items. Unless otherwise specified, the following emergency repair items shall be furnished with each tank:

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<u>Item</u>	<u>Quantity</u>
Clamp, sealing	4 ea
Clamp, sealing	2 ea
Clamp, sealing	2 ea
Plug, tapered, wood, 5 inch	2 ea
Plug, tapered, wood, 3-inch	2 ea
O-ring for access door fitting	2 ea
O-ring for vent and drain fittings	2 ea

3.7 Identification marking. The tank shall be identified by means of an identification label located as shown in Figure 1. The label shall be made of coating compound as specified in 3.3.2 and shall be bonded to the tank. The following information shall be molded, either recessed or in relief using 1/2 inch (minimum) letters, on the tank identification label:

TANK, FABRIC, COLLAPSIBLE
EXPERIMENTAL
SERIAL NO.: (Specify)
MFG: (Specify mfg name and location of plant)
WEIGHT EMPTY: (Specify Approx No. of pounds)
CONTRACT OR ORDER NO.: (Specify)

3.8 Workmanship. Workmanship shall be of the highest quality and shall permit no defects adversely affecting the strength or serviceability of the finished tank. The reinforced fabric flange-type fittings shall contain no gum voids, cracks, or tears, that could adversely affect the strength of the assembly. All metal parts shall be clean and free of sand, dirt, scale, and flux. Surfaces shall be smooth with edges rounded or beveled. The inside and outside of the tank shall be clean and free of foreign materials. Any necessary repair or rework shall restore the reworked area to its full strength and shall meet all applicable requirements of this specification. The cemented surfaces of all spliced areas, fitting flanges, and patch-type

repairs shall effect a bond that will result in strength of the cemented area not less than the strength of adjacent tank fabric. The tank seams shall exhibit no evidence of separation (peel back) greater than 1/4 inch or seam slippage greater than 1/8 inch.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government.

4.1.2 Component and material inspection. The supplier is responsible for insuring that components and materials used are manufactured, examined, and tested in accordance with referenced specifications and standards.

4.2 Test Samples.

4.2.1 Preparation of Test Samples. All test samples (materials, sub-assemblies, and fittings) offered by the supplier for testing shall have been made of materials, construction processes, and curing identical to those used in the manufacture of the tanks represented. Curing of the samples shall be accomplished in the same equipment, e.g. press, autoclave, etc, and identically as to time, temperature, pressure and environment, e.g. steam, air (humidity) gas etc, to that to be used in the production of tanks.

4.2.2 Samples prepared as in 4.2.1 shall be of sufficient quantities to perform all the tests listed in Tables I through V and to provide duplicate samples of the type specified to the U S Army Mobility Equipment Research and Development Command, Attention: DRDME-GS, Ft Belvoir, VA 22060.

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4.3 QUALITY CONFORMANCE INSPECTION

4.3.1 Destructive tests. For each lot of the same size tanks offered by the supplier, one set of samples shall be prepared as in 4.2 and tested to verify conformance with Tables I through V. Failure on any test may be cause for rejection of the lot of tanks.

4.3.2 Assembly examination. Each complete tank produced shall be examined as specified in Table VI. Any nonconformance revealed by the inspection shall be cause for rejection.

4.3.3 Assembly tests One scale model tank shall be selected at random from each lot of same size tanks and tested as specified in 4.3.3.1 through 4.3.3.6.1.

4.3.3.1 Vent assembly. Subject the vent assembly to an internal pressure of 3 inches of water. Inability of the pressure relief cap to open at this pressure shall constitute failure of this test.

4.3.3.2 Tank handle pull resistance. Apply a force of 1,000 pounds for 1 minute to the tank handle while the material to which the handle is attached is held securely. The pull shall be in a direction perpendicular to the plane of the handle patch. Any damage, permanent distortion, or separation of the handle, patch, or tank material shall constitute failure of this test.

4.3.3.3 Low temperature. Fold two scale models in thirds and roll the first tank on a 15 in dia corrugated steel pipe with 18 in dia dimension of fitting parallel with pipe longitudinal centerline. Hold tank on pipe with one loop of nylon bleeder tape. Install on test bed with fitting located 90° from top of roll. Install 130 lbs of weight inside the mandrel over the folded tank. On the second folded tank roll the ends toward the center using two

folds each and cover with a piece of 3/4 in. plywood and place 320 lbs of weight on the plywood. Place in cold box at $-30^{\circ}\text{F} \pm 2^{\circ}\text{F}$ for 24 hours. Raise temperature to $-25^{\circ}\text{F} \pm 2^{\circ}\text{F}$ for an additional 22 hours. At the end of this period while still at -25°F , the tank shall be slowly unfolded. Flaking, cracking, or separation of the coated fabric shall constitute failure of this test.

4.3.3.4 High temperature. The procedure for the high-temperature test shall be the same as that specified in 4.3.3.3 except that the temperature shall be 160°F plus or minus 2°F , for a period of 24 hours. Damage to the coating, separation of surfaces shall constitute failure of this test.

4.3.3.5 Water Storage. Fill the tanks with 250 gallons of water and allow to stand for 24 hours ± 2 hours. Any evidence of leakage or seepage shall constitute failure of this test.

4.3.3.6.1 Internal inspection. The tanks shall be inspected internally after the water storage test of 4.3.3.5. Any evidence of weakened areas, coating or barrier delamination shall constitute failure of the overload test.

4.4 TEST DETAILS

4.4.1 Existent gum. Cut a 5-gram specimen of each tank interior coating compound into approximately 1/16-inch squares and place in a flask containing 250 ml of ASTM D-471 REFERENCE FUEL D, and allow to stand for 48 hours at 73°F . Decant and filter the contaminated fluid through Whatman 41H filter paper or equal. Determine the unwashed existent gum content of the filtrate in accordance with ASTM D381-70, procedures 9.1 through 9.7 using the air jet vaporizing medium and an evaporation time of 45 minutes. Determine the heptane washed gum in accordance with ASTM D381-70 procedures 9.8 through 9.12.

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4.4.2 Diffusion. The test apparatus shall consist of a diffusion cup and ring in accordance with MIL-T-52983. Cut a circular test disk of coated fabric to conform to the outside diameter of the cup flange. Punch holes in the disk to correspond to the flange bolt dimensions. The cup shall be filled with approximately 40 ml of ASTM D-471 REFERENCE FUEL D. A nylon solution may be used for sealing the test disk to the diffusion cup flange. The test disk shall be placed over the cup with the tank "interior" side towards the test fuel. The bolts shall be tightened securely. Place the diffusion cup in a suitable rack in a constant temperature of 73.5⁰F. plus or minus 2⁰F. and a relative humidity of 65 percent. Allow 1 hour for the assembly to reach equilibrium, then weigh the cup to the nearest 0.005 gram and place in the rack with the cup face upward. Keep the cup at the above constant temperature and humidity for 24 hours. Then weigh and check for vapor loss. Retorque the bolts if necessary. Invert (test disk down) the cup in a rack that permits free access of air to the test disk. Weigh the cup daily. Defective films or leaks caused by faulty assembly are usually found when the cup is weighed on the third day. Continue to weigh the cup daily until the weight loss is constant to within .010 grams per day after two 24 hour periods. Then record daily weight loss for a continuous interval of 72 hours. The diffusion rate (D) in fluid ounces per square foot per 24 hours shall be calculated from the following expression:

$$D = \frac{144 \text{ (average daily loss in grams)}}{(\text{Sp Gr})(29.573)(3.142)(R^2)}$$

where Sp Gr is the specific gravity of the test medium and R is the inside radius of the test cup.

4.4.3 Puncture resistance. Method 5120 of FED TEST METHOD STD No. 191 applies except that the ring clamp mechanism shall have an internal diameter of 3.00 inch, and the ball shall be replaced by a piercing instrument shaped like a flared, flat-tip screwdriver, having a width of .312 plus or minus .010 inch and a thickness of .031 plus or minus .004 inch at the extreme tip. The piercing tip edges shall be rounded to a .01 inch radius. The piercing instrument shall be oriented to intercept the warp and fill threads at an angle of approximately 45 degrees. The average of three test specimen shall be reported.

4.4.4 Low temperature crease resistance. Fold two coated fabric specimens each 4 inches square in half in both directions with the folded corner occurring at the center of the specimens. Place each folded specimen under a 4-pound load and condition at minus 25⁰F for 46 hours. At the end of the conditioning period, unfold the specimens while still at a temperature of minus 25⁰F and examine visually. Signs of cracking, peeling, or delaminating of any coating material shall constitute failure of this test. If the specimen does not fail, then subject the specimen to the diffusion test specified in 4.4.2 except position the specimen in the diffusion cup in such a manner that the center of the previously folded specimen coincides with the center of the cup. Nonconformance to Table III shall constitute failure of this test.

4.4.5 Blocking. Place two coated fabric specimens 6 inches by 1 inch in an oven on a smooth surface in such a manner that the ends are overlapped 1 inch. Place a 4 pound weight directly on the overlapped area. After conditioning a temperature of 158⁰F plus or minus 2⁰F for 4 hours, remove the weight and take the specimens from the oven and condition for 1 hour at 73.4⁰F plus or minus 3.6⁰F. Attach one end of the specimen in a suitable clamping device allowing the free end to hang down. Suspend a 4 ounce weight from the free end of the specimens. Inability of the strips to separate within 5 seconds under the 4 ounce load shall constitute failure of this test.

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4.4.6 Coating adhesion. Samples of coated fabric shall be bonded face to face to provide specimens for determining adhesion between the fabric and exterior coating(s); between the fabric and interior coating(s); between laminations of interior coatings and barrier (if used), and between laminations of exterior coatings. In forming this bond the specimens shall be subjected to no heat or pressure other than that normally encountered in curing the coated fabric, except for minimal pressure necessary to insure contact while the bond is setting.

4.4.6.1 Test procedure. The adhesion shall be determined in accordance with method 8011 of FED TEST METHOD STD No. 601 except that the specimens shall be 2 inches wide. The specimens shall be of sufficient length to conduct adhesion tests for both initial values and after fuel or water immersions. The adhesion results obtained on each immersed specimen shall be compared with the initial adhesion of the same specimen to determine percentage of adhesion retained. The reported adhesion and percent retention shall be the average of not less than two specimens. Attempts shall be made to cut the coating back to the fabric and to determine the adhesion value at the coating-to-cloth interface. However, if a specimen separates at a plane other than the bond of the coating to cloth (such as between layers of coating materials or between barrier film and coating) the adhesion value and the plane of failure shall be recorded. Immersed specimens shall be conditioned in the test fluid at 73°F plus or minus 5°F, for 30 to 90 minutes before testing. Testing of immersed specimens shall be completed within 3 minutes after removal from the conditioning fluid. Immersion of specimens shall be in accordance with method 6001 of Federal Method Standard No. 601. Nonconformance with Table III shall constitute failure of this test. Any obvious bond failure evident after immersion but before stressing, even if the plane of failure is not sandwiched between the layers of coated fabric shall constitute failure of this test.

4.4.7 Seam tests. The bonding together of any two or more pieces of coated fabric (such as lap joints, butt joints, end closures, chafing patches, coated

fabric flanges of fittings, etc) shall be considered as seams and shall be subjected to all seam tests specified herein. The average breaking strength of five specimens for each type seam for each test will be reported for conformance to Table IV. Breaking strength specimens shall be 2 inches wide (parallel to the seam) and shall extend (perpendicular to the seam) 3 inches beyond both edges of the seam. No part of the test specimens shall be coated or covered during the fuel or water immersion periods. Specimens shall be cooled in the immersion fluids at 73° F plus or minus 5° F for 30 to 90 minutes before testing. Testing of immersed specimens shall be completed within 3 minutes after removal from the immersion fluids. The average peel adhesion strength of two specimens for each type seam will be reported for conformance to Table IV. Peel and adhesion specimens shall be sufficient length to determine both the initial and after fuel or water adhesion values on the same specimen. If seam construction involves the use of binding thread, then the peel specimens shall be prepared with threads removed.

4.4.8 Dead load shear resistance. The test specimens shall be 1.0 inch plus or minus .02 inch wide (parallel to the seam) and shall extend a minimum of 3 inches on each side of the seam. One index mark shall be scribed on each side of the seam to facilitate observation and measurement of slippage. Each specimen shall be subjected to a constant (dead load) tension force of 50 pounds plus or minus 1/2 pound at 200° F plus or minus 2° F. After 8 hours examine each specimen while still under tension for signs of slippage or separation. Three specimens shall be tested for each determination. Slippage, by any specimen, greater than that specified in Table IV shall constitute failure of this test.

4.4.9 Strength of bonded fittings. Specimens shall be prepared by cutting through the aluminum flange such that parallel 1.0 inch wide sections are obtained from the straight portion of the oval fitting and 1.0 inch wedge shaped sections are obtained from the vent (or drain) and the curved portion of the oval fitting. The 1.0 inch shall be measured

as a chord passing through the midpoint between the inside and outside diameters of the flange wedge. If supplier's alternate fittings are specified, samples shall be cut similarly to the above description providing 1.0 inch specimens measured at a chord midway between the internal and external radii.

4.4.9.1 Initial bond strength. The coated fabric flanges shall be fastened together in one jaw of the test machine so that the jaw will be at least 1.0 inch from the nearest part of the aluminum flange. The aluminum flange shall be secured in the other jaw of the test machine and this jaw shall clamp only the aluminum and shall not compress the embedded part of the coated fabric between the metal flanges. The jaws shall be separated at a rate of 1.0 inch per minute at 75°F plus or minus 5°F. The average of five test specimens shall be recorded as pounds per inch of width.

4.4.9.2 Bond strength after fluid immersion. Five test specimens shall be immersed for the appropriate durations in each test fluid specified in Table V. No part of the specimens shall be covered or coated during immersion. Specimens from both the oval and vent/drain fittings shall be included in each test fluid. The test specimens shall be cooled in the immersion fluid to 75°F plus or minus 5°F for up to 60 minutes. The specimens shall be removed from the test fluid, one at a time and tested as in 4.4.9.1. Each test shall be completed within 3 minutes after removal from the test fluid. The average of five tests for each fluid shall be reported in pounds per inch of width.

4.4.9.3 Dead load shear resistance aluminum to fabric bond. Three specimens shall be clamped as in 4.4.9.1 and subjected to a constant (dead load) tension force of 50 pounds at 200°F plus or minus 5°F. At the end of 8 hours the specimens shall be examined for slippage or separation while under tension.

4.4.10 Peel adhesion of aluminum to coated fabric. Special test specimens shall be fabricated consisting of aluminum strips bonded to lengths of coated fabric. The aluminum strip shall be 12 inches long (min) by 2.0 inch plus or minus .05 inch wide by 1/8 inch thick and shall be of the same alloy as that used in the aluminum fitting flanges. The coated fabric shall be 12 inches long (min) by 2.0 inch plus or minus .05 inch wide and shall be of the same composition (and or the same state of cure before bonding) as that used in the coated fabric flanges. The coated fabric strip shall be uniformly bonded to the aluminum strip. The bond shall be formed using identical techniques and bonding agents used to bond tank fittings and shall be cured identically (time, pressure, temperature, etc) to the process used in bonding tank fittings.

4.4.10.1 Test procedure. Specimens shall be tested as per method 8031 of FED TEST METHOD STD No. 601. Two specimens shall be averaged for each fluid immersion test. The same identical specimens shall be used to determine the initial peel strength and the strength after fluid immersion and when computing the percentage of initial adhesion retained.

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